William Antus

Plan a dashboard for energy measuring, improve overview of energy consumption, and increase energy recovery

School of Technology and Innovations
Master's Thesis in Smart Energy Programme

Vaasa 2023

UNIVERSITY OF VAASA
School of Technology and Innovations
Author: William Antus
Title of the thesis: Plan a dashboard for energy measuring, improve overview of energy consumption, and increase energy recovery
Degree: Master of Science in Technology
Discipline: Smart Energy
Supervisors: Miadreza Shafiekhah, Hannu Laaksonen
Year: 2023 **Pages:** 67

ABSTRACT:

This thesis is written on behalf of a manufacturing company, focusing on energy consumption, recovery, and management. The energy sector continuously changes through carbon emission targets and laws demanding action from companies in the transition to renewable energy resources. Therefore, companies target more innovative manufacturing solutions by measuring, controlling, and visualising energy consumption. Furthermore, the unstable and fluctuating energy situation, rising energy costs, and customers demanding sustainably produced products have enhanced the interest in energy questions at the company. Accordingly, the desire is to improve the overview of energy consumption, improve energy efficiency, and enable energy recovery through storage. Currently, energy measurements are limited to monthly reports based on historical data. This thesis attempts to overcome this by presenting a system providing all stakeholders access to real-time operational data. The energy management system with a dashboard visualising energy consumption and performance indicators could be used to plan production cycles, adjust product prices, and perform predictive maintenance more accurately.

The method used in this thesis is qualitative research through interviews with stakeholders at the company. Based on the interview results, a dashboard design is developed through three different layouts, customised for all stakeholder groups. In addition, the proposed energy management system enables visualising collected real-time data in dashboards. The theoretical framework in this thesis is a literature review of scientific research in energy management, dashboard design, energy recovery, and storage. Previous research in energy management presents several implemented technologies improving efficiency, reliability, and stability in the energy supply.

The thesis result includes an interview analysis, an energy management system, a dashboard design, and an energy storage system. The interview gives comprehensive knowledge to identify significant performance measures, experience, and interest from stakeholders in the field. The resulting energy management system is an IoT system with collecting assets, an edge platform, a database, and dashboard visualisation. The proposed energy storage system uses thermal energy storage technology with sand as a storage medium. This solution could be driven by renewable energy resources as primary energy resources and implemented to store recovered energy as secondary energy resources improving energy efficiency.

In conclusion, this thesis proves that an energy management system with a dashboard visualising collected energy data could be implemented. Furthermore, this thesis concludes that involved stakeholders effectively provide knowledge and experience in the development process of customised dashboard designs.

KEYWORDS: energy management system, dashboard design, energy storage system, energy efficiency, stakeholders, IoT, edge computing, big data.

Contents

Figures

Tables

Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
EMS	Energy Monitoring System
FAPS	Factory Automation and Production Systems
GDP	Gross Domestic Product
IoT	Internet of Things
IIoT	Industrial Internet of Things
ISW	Industrial Solid Waste
IT	Informational Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
MES	Manufacturing Execution System
MSW	Municipal Solid Waste
MQTT	MQ Telemetry Transport
NIST	National Institute of Standards and Technology
OT	Operational Technology
PLC	Programmable Logical Computer
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SEM	Smart Energy Management
SHS	Sensible Heat Storage
TES	Thermal Energy Storage
TIEM	Totally Integrated Energy Management
WTE	Waste-to-Energy

1 Introduction

The energy sector continuously changes, creating further challenges and opportunities for industrial manufacturing. Among the challenges are rising energy costs, requirements on carbon emissions, and political and economic interests. In comparison, industrial automation and emerging intelligent technology contribute opportunities to enable the implementation of renewable energy resources. According to J. Li et al. (2023), the share of renewable energy is forecasted to grow by 147% globally during the next 30 years. In addition, renewable energy directives from the EU target a level of renewable resources of a minimum of 32% by 2030 and accomplish climate neutrality by 2050 (Directorate-General for Energy, 2020). Future requirements are forcing companies to increase sustainable operations. Therefore, growing number of projects within energy recovery, energy management, and energy storage implementations are essential for the energy sector in the future.

Historically, before the 1990s, industrial manufacturing relied entirely on operational technology (OT), including programmable logic controllers (PLC) and sensors. During the 1990s, the development of IT systems increased rapidly through MES and ERP technologies. Current innovation involves connecting IT and OT assets creating more flexible, reliable, and smarter manufacturing (Wegner, 2023). Furthermore, advanced industrial automation enables intelligent manufacturing through utilising Internet-of-Things technologies, big-data collection, machine learning, and artificial intelligence.

In order to stay competitive, intelligent energy management systems are implemented to improve manufacturing processes. Energy management systems target to measure energy consumption at every step of the manufacturing process (Javied et al., 2015). Intelligent automation enables the measured data to be collected, analysed, and transported through cloud or edge systems and visualised on dashboards. Collected production data provides insight into the manufacturing process, where the energy is consumed and how the process could be improved. In addition, the implementation of an energy management system could reduce energy costs, improve productivity, and enables measuring impacts from improvement actions.

This research is essential for the transition to Industry 4.0 generation by designing a new and developed dashboard based on real-time energy consumption measurements. Javied et al. (2018) present a research example of an energy management system based on a cloud structure compatible with Industry 4.0 plants. The research concludes that energy management systems could effectively improve energy efficiency in manufacturing industries.

Furthermore, this research aims to identify further energy storage and recovery opportunities, involve energy consumption in product cost calculations, and improve energy efficiency. Firstly, measuring and collecting data is essential to identify energy consumption factors. The manufacturing process consumes energy through heat, electricity, steam, and pressured air. The collected data should is then transported and stored for further analytics. Finally, different dashboard designs visualise the data based on requirements from the stakeholders.

1.1 Background

This thesis is performed as a project on behalf of Company X to develop an energy management system with dashboards and data collection. Furthermore, the work focuses on optimising energy consumption, increasing energy recovery, and improving production processes. The unstable and fluctuating energy situation, rising energy costs, and customers demanding sustainably produced products have enhanced interest in energy questions in Company X.

1.2 Research problem

The manufacturing industry demands a high amount of energy for the manufacturing process. Accordingly, efficient energy consumption has a significant effect on the business of the company. In addition, manufacturing processes could be more sustainable using more renewable energy resources. Furthermore, the energy consumption overview should be monitored in real-time based on accurate data and performance indicators. Currently, the collection and utilisation of measured energy consumption are limited and reported monthly.

1.3 Research purpose

The research objective is to develop an energy management system with a dashboard visualising energy consumption and performance indicators in manufacturing. The system should enable effective planning-, measurement- and controlling tools. This research aims to find efficient measuring tools for data visualised in a dashboard showing energy consumption in manufacturing. By collecting data with real-time measurement methods visualised in dashboards, actions can be taken to improve operations, decrease energy consumption, and product prices can be adjusted more accurately. In addition, the objectives are to identify energy-consuming factors, enabling more energy recovery and creating more sustainable and environmentally friendly manufacturing. Accordingly, the following research questions are stated:

- How to improve energy consumption measurements?
- How could energy recovery rates increase?
- What kind of energy management system could be implemented to improve energy consumption efficiency?
- How could real-time collected data be visualised from the manufacturing process?
- What layouts, information, and reports should the dashboard provide from different stakeholder perspectives?

1.4 Constraints

The research is constrained to one machine in the manufacturing process, which could later be implemented for other machines. The collected data will be constrained to important energy parameters for the process. Energy measurements are limited to the manufacturing process at the machine, while other energy-consuming factors in the building are not considered.

1.5 Confidentiality

For data security reasons, all confidential information about the company was removed from the public version, and the company name is referred as “Company X”. Also, after writing the transcript, all interview recordings are deleted.

1.6 Thesis structure

This thesis is divided into seven main chapters: Introduction, Literature Review, Methodology, Data Visualisation, Result, Discussion, and Conclusion. Chapters two and three present the theoretical part, while Chapters four and five are the Empirical part of the research. Finally, Chapters seven and eight summarise, conclude, and discuss the research outcome and future possibilities.

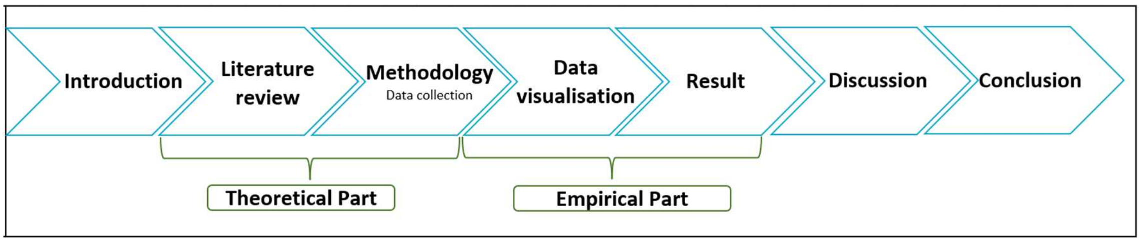

Figure 1. Thesis structure.

1.7 Equations

Some basic equations in this research calculates essential energy consumption values. The mean rate of heat energy equation.

$$Q = \frac{m \times c_p \times \Delta T}{t} \ , \qquad (1)$$

where

Q = Total energy amount [kJ/s]

m = Substance mass [kg]

c_p= Specific heat capacity of the fluid [kJ/kg°C]

ΔT= Temperature difference of the substance [°C]

t = time [s]

Energy consumption is determined based on the machine power and the time it is operating in the following equation.

$$E = P \times \left(\frac{t}{1000}\right), \qquad (2)$$

where

E = measure energy [kWh]

P = power units [W]

t = time [h]

The specific energy consumption (SEC) equation below calculates the ratio of energy used for producing a product during a specific time. The unit for SEC depends on which energy type it is intended to calculate. For example, electricity use unit GWh/t and heat GJ/t, where t represent tons of produced products (Lawrence et al., 2019).

$$SEC = \frac{J \times E_t}{P_t}, \qquad (3)$$

where

J = Energy consumption unit [GWh] or [GJ]

P_t= Produced quantity [ton]

E_t= Consumed energy

2 Literature review

This chapter presents the theoretical framework for this research. The review introduces past research on topics related to conducting the research. First, a review of research on several emerging technologies enabling energy management system implementations in the transitions to Industry 4.0 generation. Second, review of essential energy storage and recovery research in manufacturing. In addition, the review includes research regarding data collection properties and dashboard designs for data visualisation. Finally, the chapter ends with a summary.

2.1 Energy Management

The demand for more environmentally friendly and sustainable solutions for manufacturing processes utilising developed automation technologies is increasing. Wegner (2023) describe customisation, regionalisation, digitalisation, and sustainability as current trends in the manufacturing industry. Accordingly, smart factories enable more flexible manufacturing based on customer demands and future requirements.

Implementing energy management systems is a part of the transition to smart factories with more intelligent manufacturing. Energy Management Systems (EMS) are implemented to ensure efficiency, reliability, and stability in the energy supply. In addition, more data require efficient and intelligent cloud-based solutions (Javied et al., 2018). Smart manufacturing is defined by The National Institute of Standards and Technology (NIST) as follows:

“Fully integrated and collaborative manufacturing system that responds in real-time to meet the changing demands and conditions in factories, supply network, and customer needs” (Rathnam, 2019).

Smart manufacturing enables more efficient information and reports about every part of the manufacturing process in real-time. Furthermore, it works as a platform for communication between assets and systems for transferring data. Automation systems accomplish the transition to more intelligent manufacturing, and state-of-the-art technologies are considered in this research; artificial intelligence, machine-to-machine, internet-of-things, and machine learning. Smart factories are the practical example of the fourth industrial generation enabling business and production processes to collaborate efficiently and optimistically without human interaction (Rathnam, 2019).

Several data collection systems have been developed for performance measurements in energy-related cases in recent years. The target for implementing an energy management system is ensuring the energy supply for the manufacturing process while ecologic and economic aspects are respected. Furthermore, Javied et al. (2018) point out that EMS enable new technologies for controlling, measuring, and defining essential energy parameters. Still, there are uncertainties for EMS implementations regarding data security and industrial standards. Most energy management systems are currently based on the international standard DIN EN ISO 50001. The standard describes potential improvements in energy consumption, usage and efficiency in companies with requirements for energy consumption (Javied et al., 2018).

The emerging Industry 4.0 enables more flexible and accurate measuring and monitoring of the production process (Javied et al., 2018). The modern industry 4.0 generation relies on sensors and systems compatible to efficiently analyse, adapt, and save a large amount of data (Javied et al., 2018). To summarise, the fourth industrial revolution is the transition to an intelligent industry based on digital technology, visualised in Figure 2.

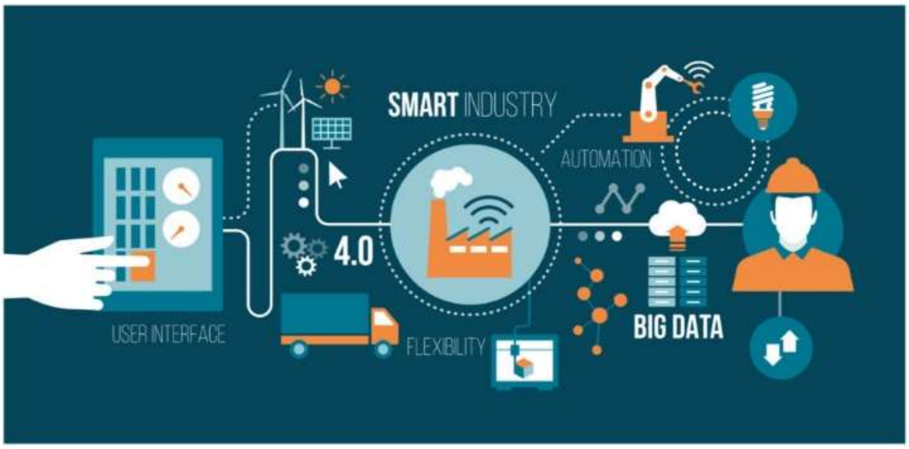

Figure 2. Visualisation of the smart factory structure (Rathnam, 2019).

2.1.1 Internet-of-Things

The transition to the Industry 4.0 generation is featured by digitalisation and automation, accomplished by Internet-of-Things (IoT) technology. Dastbaz & Cochrane (2019) define the Internet of Things as the backbone for a more connected world with increased numbers of personal and industrial devices connected through the Internet. Furthermore, IoT provides further opportunities for knowledge, data sharing and process exchange. IoT systems are all devices with an address or identity connected to a transmission network sharing data. Paraskevopoulos (2022) states that IoT technology is separated into three main layers (Figure 4). The three main layers are applications, middleware, and devices connected with different protocols. Currently, IoT is mainly implemented in logistics, healthcare, automotive industry, smart grid and smart cities (Chooruang & Meekul, 2018). Figure 3 presents a historical overview of computing solutions development, enabling IoT technology today. According to J. Li et al. (2023), IoT systems provide four main data features, collection, processing, visualisation, and storage.

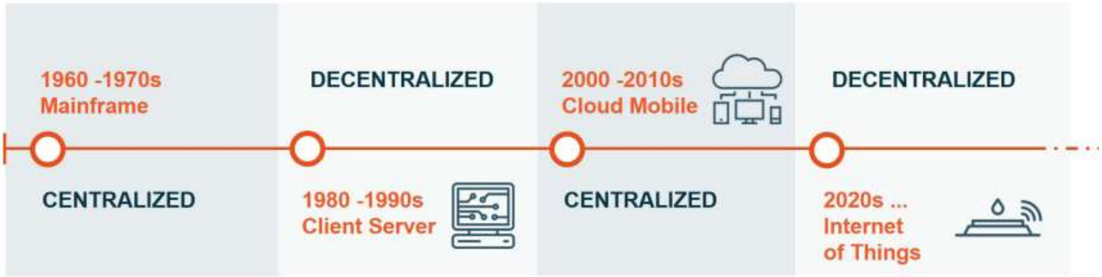

Figure 3. Historical transition of computing solutions (Maguire, 2018).

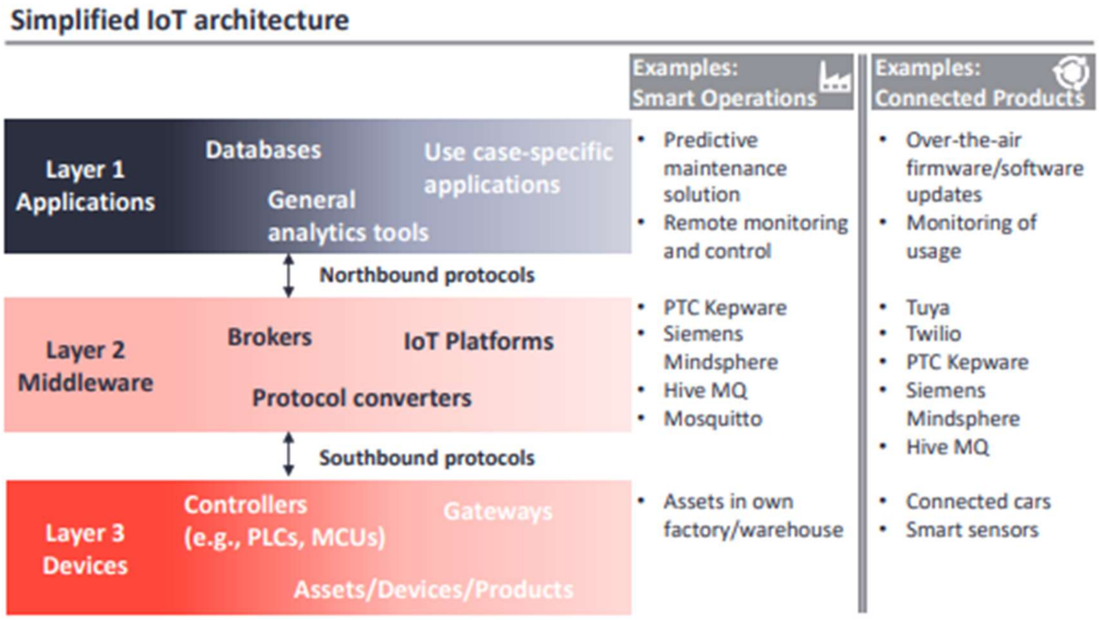

Figure 4. IoT layer overview (Paraskevopoulos, 2022).

Chooruang & Meekul (2018) discuss a system for energy monitoring with IoT design utilising a low-cost current transformer sensor, microcontroller, and an energy measurement chip to measure accumulative power consumption, active power, current, and voltage. The collected data is then sent to a server in JSON format, monitored by a current transformer providing RMS voltage and current, calculating active power and total energy usage over time or accumulative power consumption. Finally, the measured and calculated data is sent over the network through a microcontroller and stored in a local database server called InfluxDB. The user interface was established using a Grafana dashboard design to visualise the measured data as a function of time through graphs and gauges. Still, this research is limited to small-scale energy monitoring implementations.

Javied et al. (2018) assert that IoT can be utilised to develop gateways where collected data is pre-processed before it is transferred to a cloud system. Open Access, developed by FAPS institute, is an example gateway implemented in Node.JS utilising open-source software. Node.JS was developed in 2009 and is the programming language used in this research. Sufiyan (2022) describes Node.JS as a JavaScript environment enabling programming and running web applications on servers without access to the client browser. Furthermore, Node.JS is suitable for real-time data collection through fast running time and asynchronous architecture. All these features are essential for efficient IoT implementations and are utilised in a platform called Node-RED. Ferencz & Domokos (2019) utilise Node-RED (Figure 5) for creating an IIoT solution. The research concludes that the platform provides a simple user interface, fast development opportunities, and cost and time efficiency compared to other existing technologies. Furthermore, Node-RED offers dashboard tools for visualising collected data and database nodes, as presented in the figure below.

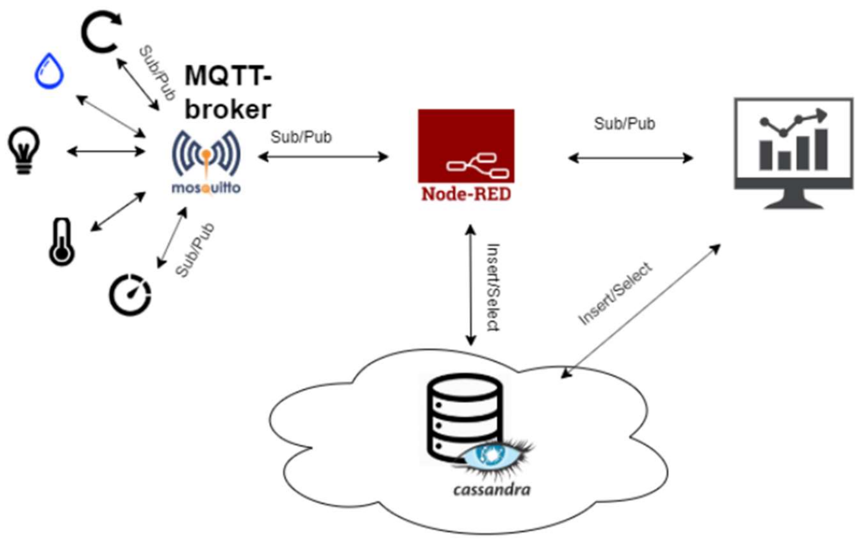

Figure 5. Example of Node-RED architecture (Ferencz & Domokos, 2019).

The main focus of this thesis is on the industrial sector of the Internet of Things, called IIoT. According to Qiu et al. (2020), IIoT focuses on manufacturing and efficiency in an industrial environment enabling smart logistics and factories. The IIoT solutions involve communication devices improving manufacturing productivity and efficiency through data collection, integration and analysing tools. Furthermore, Ferencz & Domokos (2019) assert that connectivity between all involved stakeholders, machines, platforms, and assets enabled by IIoT improves decision-making, operation security and problem-solving.

Currently, the number of implemented IIoT solutions is frequently rising due to the technology becoming cheaper and more mature. The technology includes sensors, devices, APIs, and networks, which are automation assets creating valuable opportunities for data and app implementations, improving the overview of the manufacturing process (Schaeffer, 2017).

A research example by Ren et al. (2021), essential conditions parameters from the manufacturing process are collected by IoT sensors and utilised to predict errors in the process before they occur. An IO-link module is installed to enable data transformation from the sensor to PLC. The research introduced an efficient and real-time system for data analysis and monitoring by utilising AI and Edge-computing technology. Still, there are research gaps considering the security of IIoT platforms (Ren et al., 2021).

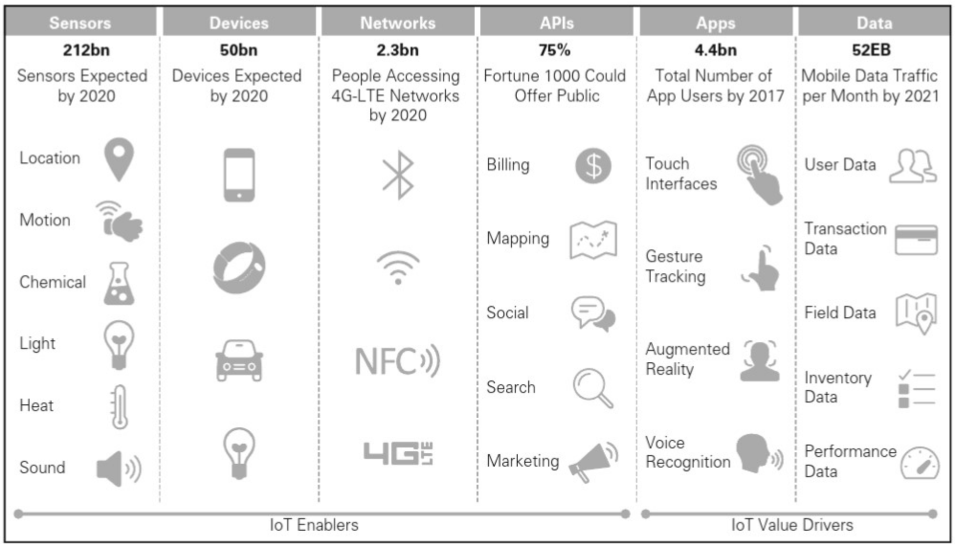

Figure 6. IIoT assets (Schaeffer, 2017)

2.1.2 Communication Protocols

The development of IoT systems in industrial manufacturing processes is enhanced by communication between machines, hardware devices and software. Communication protocols and network standards enable extensive communication. Communication Protocols are defined by Paraskevopoulos (2022) as rules enabling effective data exchange in a network between different devices. There are currently numerous communication protocols for different applications providing certain features that are important to consider.

According to Chen & Lien (2014), short wireless solutions have implemented WIFI, ZigBee, Bluetooth, and RFID connections. In larger systems, multi-hop ad hoc networking has been tested to improve energy efficiency. Wireless ad hoc networks are decentralised, transporting data through nodes connected by communication links. Gerodimos et al. (2023) provide research on developed communication protocols for IoT applications for security and energy consumption improvements. Low Power Wide Area Networking (LPWAN) and Wireless Personal Area Networking (WPAN) wireless networks with low energy consumption are divided into two technology categories.

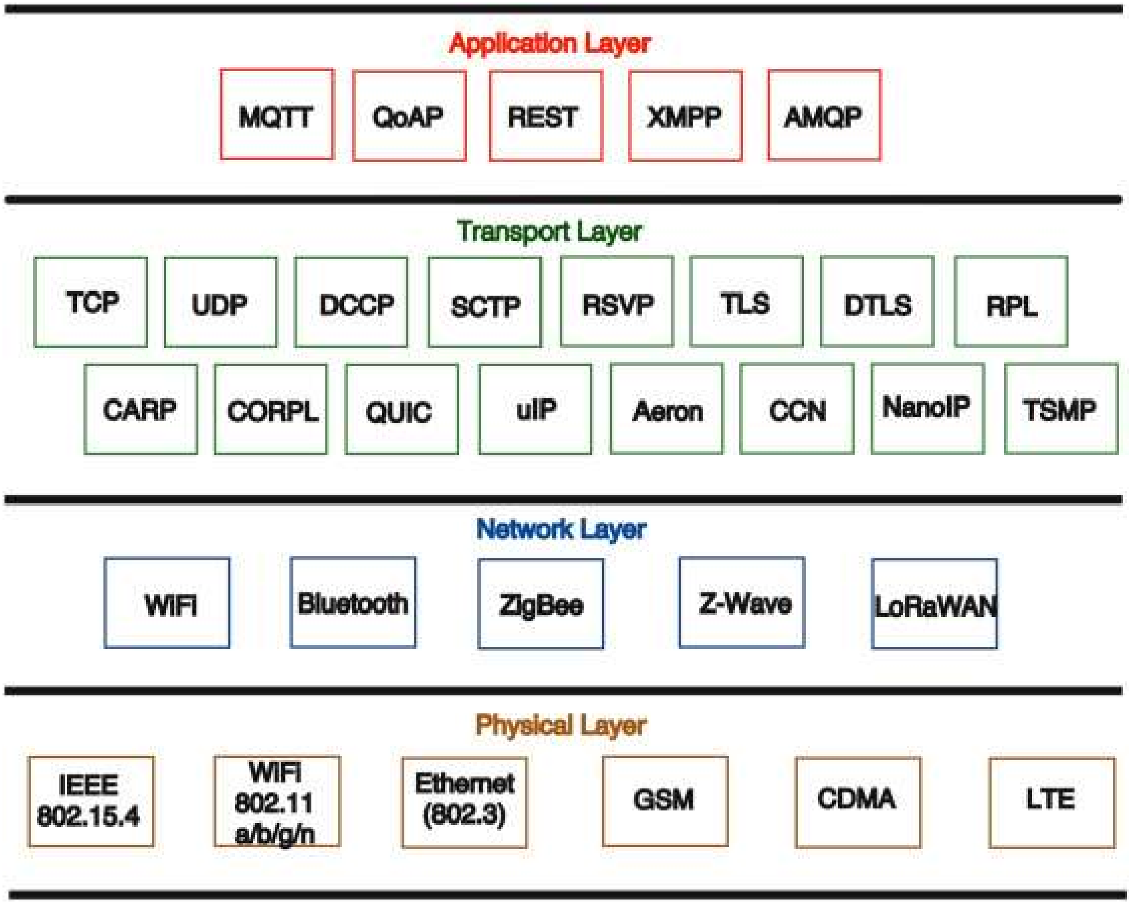

Figure 7. IoT Communication Protocols (Gerodimos et al., 2023).

The essential communication technology for this research is Machine-to-machine (M2M), which involves wireless communication transporting essential data between physical assets and the internet cyber world. Chen & Lien (2014) present a cloud-based M2M system (Figure 8) where many machines wirelessly interact, transmit, receive and collect data. The research concludes that M2M applications enable energy-efficient data transferring and communication through factory automation.

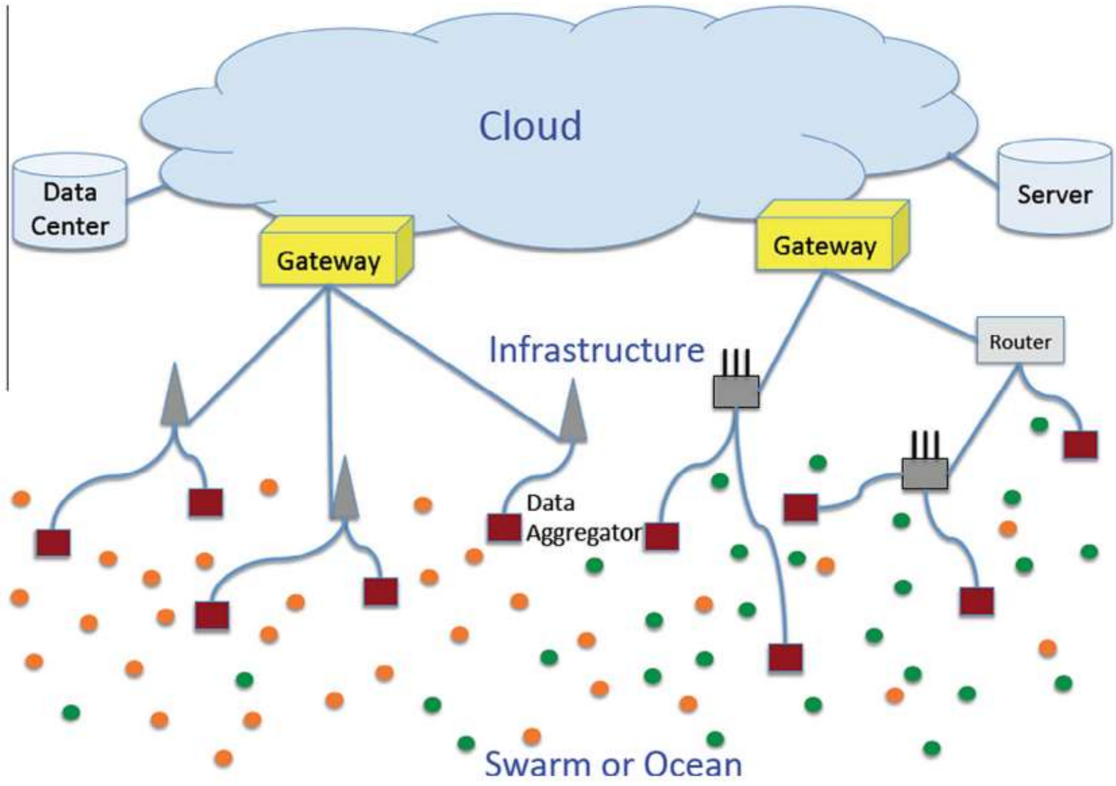

Figure 8. M2M architecture example (Chen & Lien, 2014).

2.1.3 Cloud Computing

A critical emerging technology connected to IoT implementation is Cloud Computing, defined by Microsoft as the delivery of computing services through servers, databases, networking, software, analytics, and storage. Accordingly, Cloud Computing provides flexible resources, innovations and economic benefits (Dastbaz & Cochrane, 2019). Cloud Computing is essential when the number of implemented intelligent devices is increasing, enabling visualising and analysing stored data in the industry (Ferencz & Domokos, 2019).

In research by Javied et al. (2018), a cloud structure compatible with Industry 4.0 plants is presented. The solution allows users to monitor and plan production based on collected historical load and energy data. The research utilises a frontend TIEM (Figure 8) architecture where the energy consumption data from producing electric motors is collected by sensors and utilised by controllers. The collected data is then transported to a cloud through a gateway where the data is pre-processed. The cloud structure (figure 8) combines a RabbitMQ server with an open access message broker supporting several messaging protocols, Logstash open server where the data is processed through data pipelining before sensing it further to the MySQL server where it can be stored in a database (Javied et al., 2018).

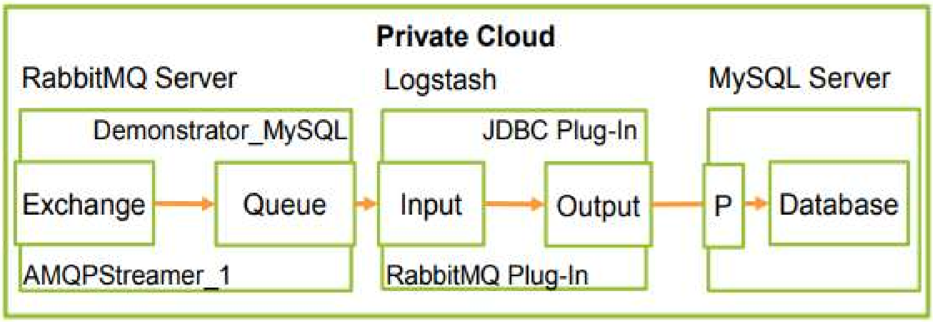

Figure 9. Cloud architecture (Javied et al., 2018).

Finally, the collected energy data is visualised and analysed by an energy management dashboard tool called TIEM (Figure 10). The objective to develop an EMS entirely integrated and automated was created at the Institute for Factory Automation and Production Systems through the PHP framework called Symfony. Based on the Symfony framework, TIEM is a tool enabling visualisation. Furthermore, TIEM is based on the international energy standard DIN EN ISO 50001 and is an abbreviation for Totally Integrated Energy Management. The research concluded that energy monitoring is essential in improving energy efficiency, and the complete energy management system is presented in Figure 11. Furthermore, the automated and private cloud solution improves the flexibility for planning manufacturing processes, processing collected data, and storing data for further analysing (Javied et al., 2018).

Figure 10. TIEM structure (Javied et al., 2018).

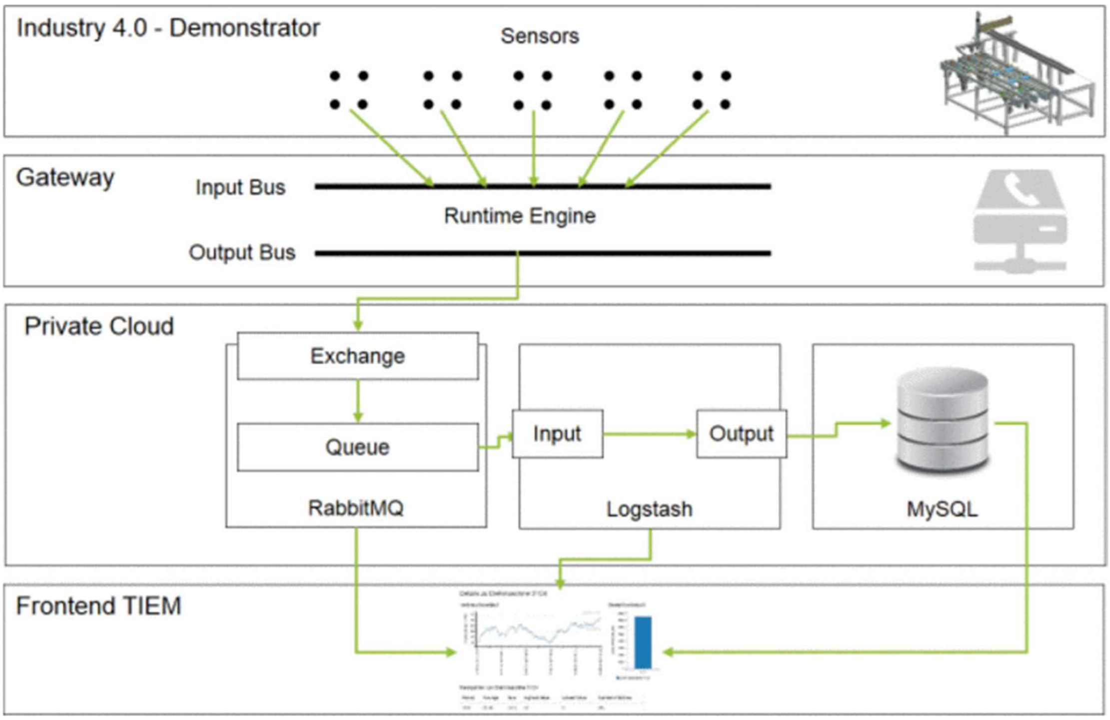

Figure 11. The EMS system architecture (Javied et al., 2018).

2.1.4 Edge Computing

Besides Cloud Computing, Edge Computing is another increasing technology enabling more efficient IoT solutions. Edge computing is still an evolving technology contributing as a complement to existing IoT and cloud computing services. Shi et al. (2015) define edge computing as follows.

“Edge computing refers to the enabling technologies allowing computation to be performed at the edge of the network, on downstream data on behalf of cloud services and upstream data on behalf of IoT services.”

Currently, the number of devices connected in IIoT-systems is increasing, which leads to more collected data. Accordingly, the ability to efficiently capture and analyse data in real-time is enabled by Edge Computing, while Cloud Computing models can only provide historical data analysis (Maguire, 2018). According to Qiu et al. (2020), the number of research on edge computing in IIoT is low due to immature technology still under development.

A case study by Yrungaray (2022) presents an example of edge computing implementation in a building and automotive material manufacturing process. The target was to complete the automated plants by improving the digital transformation providing correct data in time at the right place, and better visibility. The solution involved Litmus Edge, which provides the opportunity to effectively connect any driver, protocols, OT and IT assets. The system architecture (Figure 12) included several Litmus Edge installations on HPE GL20 gateways connected to a Litmus Edge Manager managing operations of all devices sending collected data to MES and Historian systems. The implementation improved the flexibility in production and enabled analytics in real-time with dashboards. Another advantage of the system is that it uses offline machine learning on historical data (Yrungaray, 2022).

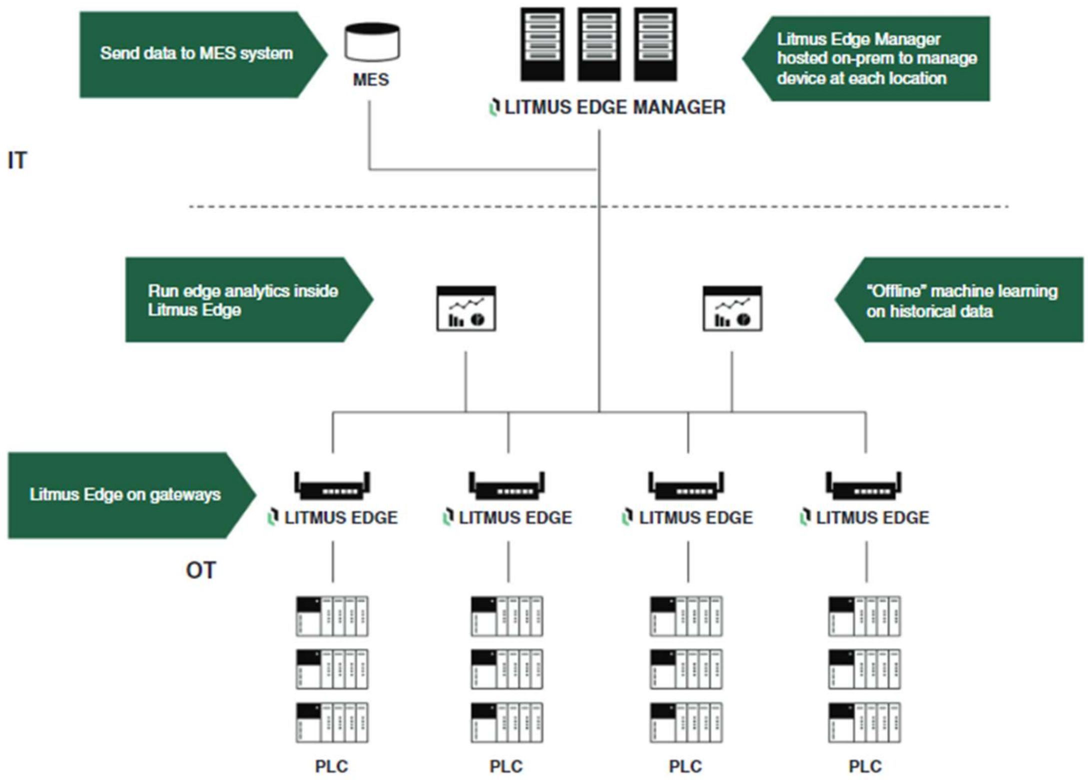

Figure 12. Example of Litmus Edge Architecture (Yrungaray, 2022).

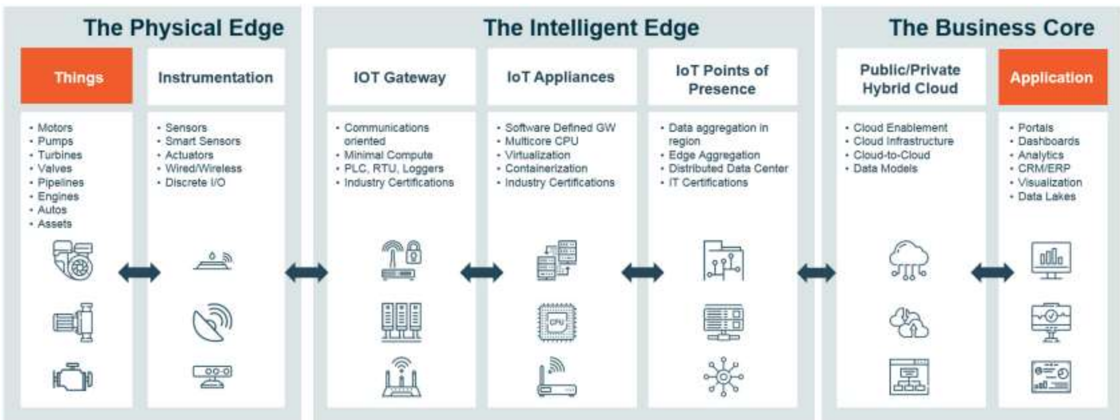

Figure 13. Edge Computing features (Maguire, 2018).

A comprehensive review of Edge Computing in IIoT by Qiu et al. (2020) presents an architecture example (Figure 14), enabling task scheduling, standardisation, data storage, and security. The system relies on large-scale data collected in real-time and transported over the network, data, and system compatibility. The research by Qiu et al. (2020) concludes that edge computing combined with other advanced technologies will be the future trend in the automation of manufacturing processes.

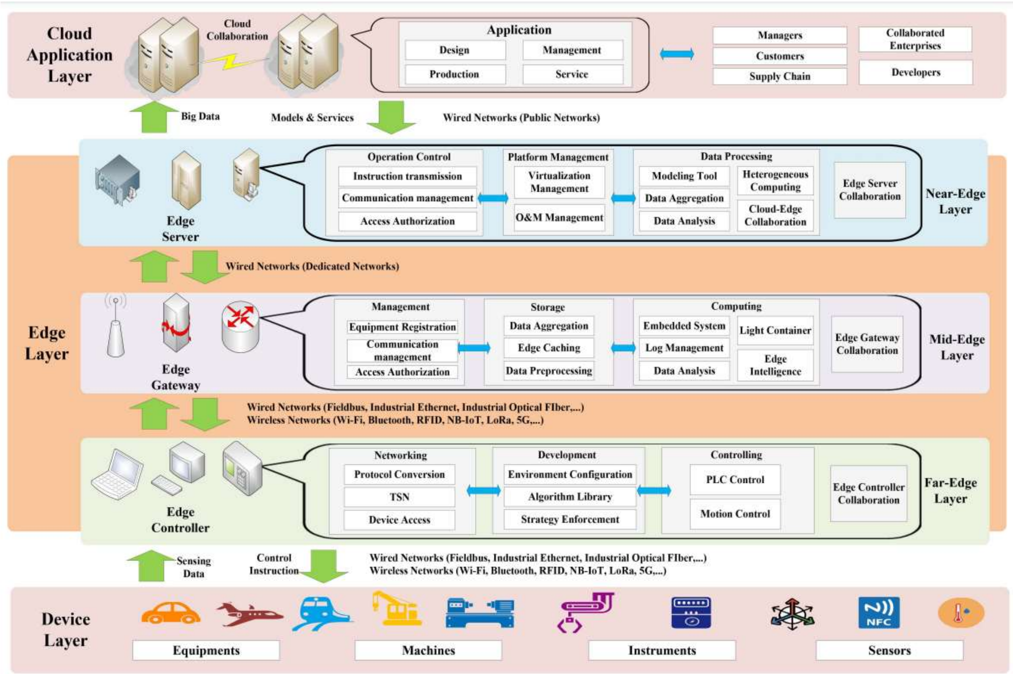

Figure 14. Edge Computing in IIoT architecture (Qiu et al.,2020).

2.1.5 Artificial Intelligence

In implementing EMS and automating manufacturing processes, artificial intelligence is an important technology enabling energy trading, forecasting, and demand response (J. Li et al., 2023). There still needs to be more research on large-scale implementations of many AI technologies in energy management to fulfil requirements. Furthermore, the training process of AI models requires a large amount of data. On the other hand, J. Li et al. (2023) points out global GDP growth and improved productivity as possible positive aspects of AI implementations.

In a research paper by Ren et al. (2021), AI and deep learning are utilised in a big data platform for real-time data analysis. The data analysis monitors production by predicting defects, facility failures, and abnormalities, enabling preventive maintenance by alerting production administrators. The proposed model (Figure 15) confirms that performance and efficiency results can be improved. By critically evaluating the source, the system's security is still an issue to investigate further.

Research by J. Li et al. (2023) review several frequently used AI algorithms in smart energy management implementations. Support Vector Machines, Neural Networks, FL, and Q-learning are introduced algorithms, which are essential to improve the performance of AI in Energy Management Systems. Furthermore, the entire digital system should be designed considering AI and Big Data features.

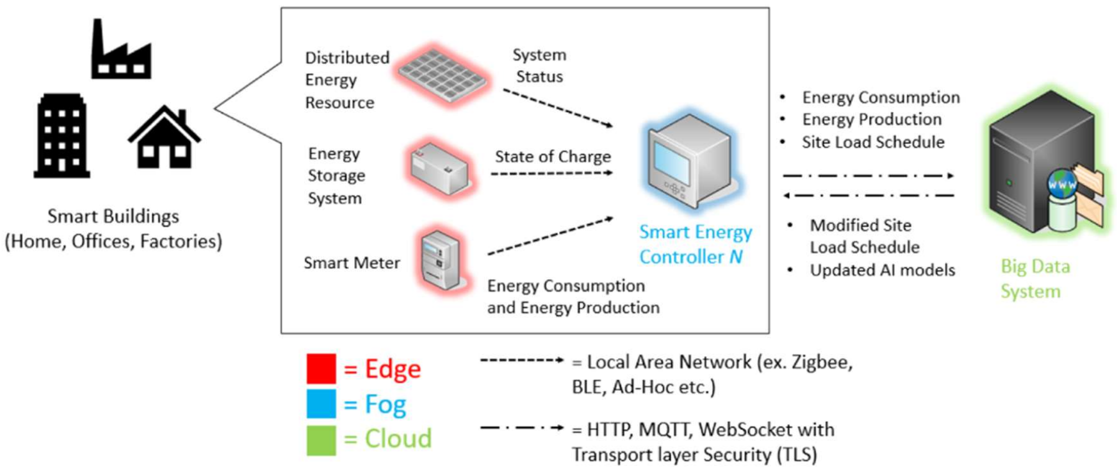

Figure 15. IoT architecture for smart energy management (J. Li et al., 2023).

2.1.6 Big data collection

The industrial transition to more automation is based on the ability to collect, organise, analyse, and store data. The amount of produced data shared across the internet is increasing. Thus, extensive data collection becomes more critical. Qiu et al. (2020) assert that big data in industrial manufacturing includes operational and production data collected by several assets from business processes. Furthermore, big data in industrial processes has the characteristics called 4V, Volume, Variety, Velocity and, Values. Efficient big data utilising data storage and analytics enables IIoT edge device development for real-time monitoring (Qiu et al., 2020).

J. Li et al. (2023) assert that in addition to real-time analytics from big data, intelligent energy systems must provide stakeholders with information from sensors, predictions, and problems to enable accurate actions. In addition, to ensure efficient big data storage, it is vital to understand the scale of the data and how it is organised and processed.

2.2 Dashboard design

According to Janes et al. (2013), the term “dashboard” first appeared in the 19th century when referring to a board avoiding mud from the carriage. Today, dashboards are referred to as systems visualising collected data for decision-making, alerting the user, and ideally supporting the user without being distracted from the actual work. Janes et al. (2013) assert two main aspects to consider when designing dashboards, visualisation technique and which data to choose. The visualisation technique is essential for acceptance and understanding from the user. An example of a typical dashboard design is presented below (Figure 16).

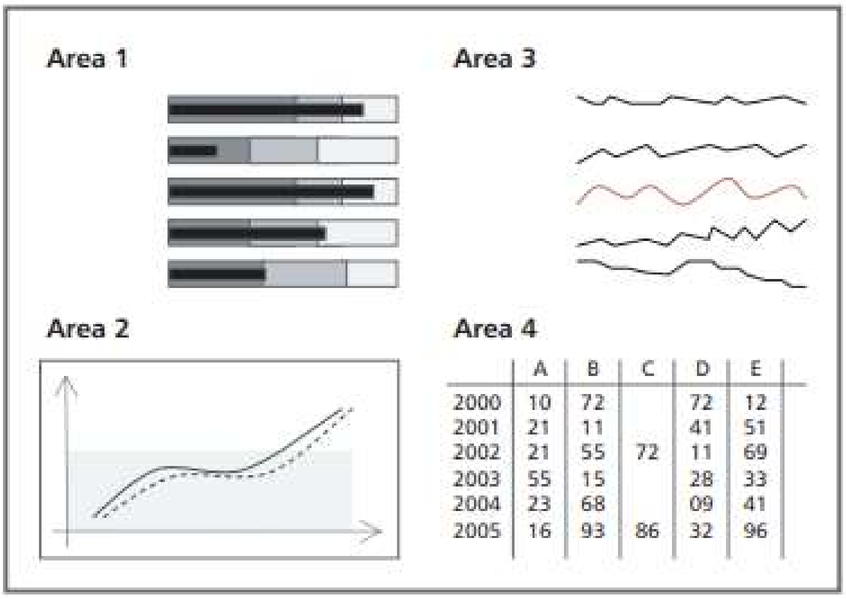

Figure 16. Examples of dashboard designs (Janes et al., 2013).

For the design of the dashboard, Janes et al. (2013) present two main approaches, “pull” and “push”. In the pull approach, the user obtains specific information, and the dashboard assists the observer in understanding the context and meaning of the visualised data. On the other hand, the purpose of the push approach in dashboards is to inform and alert the user. Furthermore, push scenarios demand the dashboard to be easily accessed, organised, and focused on the essential information without any interaction from the observer (Janes et al., 2013).

In industrial manufacturing processes, dashboards are frequently utilised to visualise data. The dashboard structure should present different values and graphs based on which stakeholder group it is expected to provide information. Furthermore, the dashboard should give a broad and clear picture of energy losses and consumption, which can be included in the cost calculations (Javied et al., 2018).

The dashboard provides essential information regarding the performance of the manufacturing process, accomplished by using Key performance indicators (KPIs). According to Wegner (2023), the target for implementing KPIs is to measure the performance of smart factories. According to Schmidt et al. (2016), KPIs have traditionally considered time, quality and costs through risk and safety estimations in manufacturing. In the transition to more sustainable operations, energy-related costs and losses have become more critical to decrease. These measurements in energy management systems include considering energy costs when determining product prices, optimising driving cycles and making energy consumption more efficient. In addition, Schmidt et al. (2016) conclude that by developing KPIs, sustainability and efficiency targets can be accomplished by developing energy performance indicators. Still, this requires an increased number of energy meters, collecting data from the manufacturing process that can be used for further analyse. In addition, the resulting values should be visualised in dashboards enabling sharing of vital information between different stakeholders in the company.

Performance indicators in energy reporting are called energy performance indicators (ENPIs). Javied et al. (2015) introduce examples of Energy Performance Indicators in Table 1. The table includes several performance indicators essential for analysing the energy efficiency of the manufacturing process. Furthermore, Javied et al. (2015) point out benchmarking and control of the company as essential features provided by energy performance indicators. Other benefits of energy performance indicators are a view of trends, details, and an overview of manufacturing. Accordingly, produced products can be evaluated more efficiently regarding energy consumption. In order to implement effective energy management, improvement possibilities in the existing operation need to be analysed. Accordingly, evaluating which ENPIs are suitable for specific manufacturing processes is essential. Sufficiently defined performance indicators can be utilised for business decisions, control methods and measurements (Javied et al., 2015).

Table 1. List of energy performance indicators (ENPIs)

EnPI	Calculation formula	Unit
Contribution of each energy carrier	$\frac{\text{Energy carrier}}{\text{Total energy}}$	%
Efficiency in internal energy conversion	$\frac{Output}{Input}$	%
CO_2 emission	$\frac{\text{Tons}}{Year}$	$\frac{\text{t}}{year}$
Share of energy costs in revenue	$\frac{Specific\ energy\ costs}{\text{Revenue (per product)}}$	%
Employees Specific energy consumption	$\frac{Total\ energy\ consumption}{\text{Number of Employees}}$	%
Area-specific energy consumption	$\frac{Total\ energy\ consumption}{\text{Heated area}}$	$\frac{\text{KWh}}{m^2}$
Production quantity specific energy consumption	$\frac{Total\ energy\ consumption}{\text{Input or Output}}$	$\frac{\text{KWh}}{t}$
Value-specific energy consumption	$\frac{Total\ energy\ consumption}{\text{Net revenue}}$	$\frac{J}{€}$
Production quantities-specific energy cost	$\frac{Total\ energy\ consumption}{\text{Produnction amount}}$	$\frac{€}{t}$
Energy intensity of a process / product	$\frac{\text{Energy consumption Process}}{\text{Total energy consumption}}$	%

Table 1. Energy Performance Indicators (Javied et al., 2015).

2.3 Energy recovery and storage

Miró et al. (2016) conclude in a review that the industry sector is one of the highest energy consumers. Therefore, energy efficiency is essential to optimise energy costs and carbon emissions from the manufacturing process. One significant factor impacting energy efficiency is the recovering rates of waste heat. Currently, there is broad potential for energy recovery in the manufacturing industry (Figure 17), which is the focus of this research. Still, existing research concludes that industrial waste heat (IWH) utilisation is low due to technical, economic, geographical, or temporary difficulties in the released energy combined with the heat demand. (Miró et al., 2016)

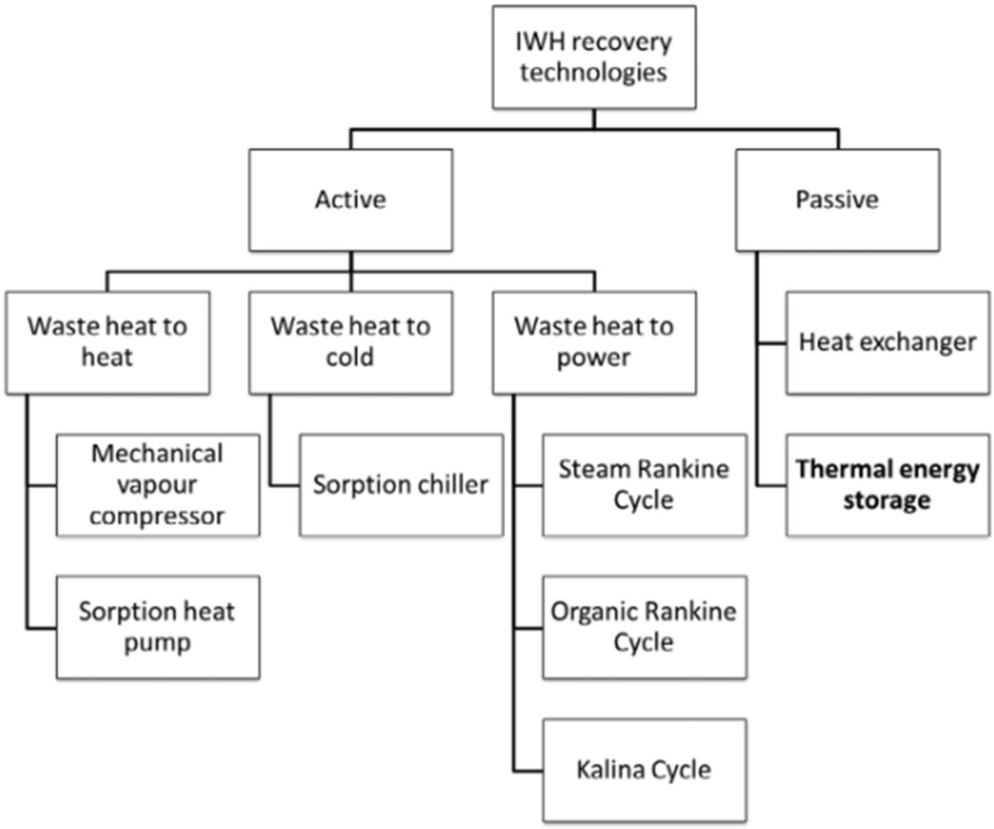

Figure 17. IWH recovery technologies (Miró et al., 2016).

In a paper by Broberg Viklund & Johansson (2014), are several alternatives for recovering and utilising excess industrial heat evaluated. The research presents the Energy Efficiency Directive (EED) from the EU, considered one fundamental aspect for developing efficient energy recovery solutions in companies. Other factors to consider are rising energy prices, supply resiliency and carbon dioxide emission levels. Heat recovery can be utilised directly for heating or converted to electricity. Furthermore, recovery technologies in the industrial sector can be classified based on their operation purpose.

Heat harvesting is the common name used for heat exchangers, heat pumps, and radiation collectors. These applications are used for transferring heat from one medium to another. Heat exchangers rely on two floating media, gas or liquids transferring heat. Radiation collectors, on the other hand, are developed to transfer radiation through a solid material, for example, solar thermal applications. Finally, heat pumps are developed to transfer heat from one cold medium to a warm medium (Broberg Viklund & Johansson, 2014).

Heat storage is used to save energy for later use where it is needed. Storing energy has an essential role in ensuring efficient energy recovery. Furthermore, connecting energy storage solutions driven by electricity from renewable energy resources improves sustainability.

Heat utilisation and conversion are essential to consider when designing energy recovering systems. According to Broberg, Viklund & Johansson (2014), heat utilisation refers to technologies where the energy is used as heat, while heat conversion technologies create electricity by converting thermal energy. Heat utilisation technology is mainly implemented for heating and cooling processes, while heat conversion includes Rankine cycles, thermoelectric generators, thermophotovoltaics, and sterling engines (Broberg Viklund & Johansson, 2014).

2.3.1 Thermal Energy Storage

Thermal energy storage (TES) is an emerging technology to overcome current difficulties in storing energy that can be used when demand occurs. Furthermore, by balancing the demand and supply, TES enables a more stable transition to renewable energy resources, solar and wind power. This research focuses mainly on Sensible Heat Storage (SHS). SHS technologies rely on a solid or liquid material heated by electricity passing through an element in contact with the storage material. It is stored and discharged during demand by piping in cool air (Z. Li et al., 2021).

TES systems can be divided into on-site and off-site. In on-site TES systems, water or steam technologies are currently most widely used, while power generation, space cooling and heating are still the most implemented applications for recovering IWH (Miró et al., 2016). Accordingly, the lack of TES used for IWH still demands large-scale implementation and offers further research.

An example of a TES based on water as a storage fluid is a heat storage tank in Berlin. The tank is 45 meters high and has a capacity of 2600 MWh by heating 56 million litres of water to 98 degrees Celsius. The plant will utilise waste heat from industrial processes and a surplus of wind power plants. The storage system will provide heat to households in the district heating network and is expected to be in commercial operation by April 2023 (Murray, 2022).

Other TES systems are based on solid materials, such as sand or engineered materials. Poulose et al. (2022) point out the high bulk capacity, easy access, reuse potential and cost as advantages with sand and metal particles as storage material. Furthermore, compared with water, the higher density in the sand allows the possibility of converting more of the stored energy to electricity from a rotating turbine generating electricity during peak demand. A drawback of creating electricity from stored energy is that the efficiency will decrease. Poulose et al. (2022) present a theoretical calculation of a storage system with manufacturing sand and engineered metal balls connected to solar power production. The result shows that the system could recover approximately 56% of produced surplus energy from the solar power plant, which improves the plant capacity (Poulose et al., 2022).

Research by Arfa et al. (2019) introduces a sand-based heat-storing battery. Sand-based solutions could replace current TES systems using molten salt as storage material that increases storage temperature, bring economic benefits, and create more sustainable storage solution. An example of sand storage is Polar Night Energy in Tampere, the first large-scale TES application that uses sand as a storage material for heat from renewable energy sources. Currently, the plant is part of the local district heating system and has an energy capacity of 8 MWh, possibly increasing to 8 GWh. The broader implementation of solar and wind power leads to surplus electricity when the demand is lower than the production, and this excess energy could be stored and recovered. IRENA (2019) points out two possible power-to-heat technologies to utilise electricity from renewable energy resources, direct conversion or heat pumps and electric boilers.

2.3.2 Waste-to-energy (WTE)

Traditionally, energy production is an industry with a significant environmental impact causing carbon dioxide emissions. Accordingly, a concept called WTE has been developed to reduce the negative impact. The concept increases the amount of energy utilised from waste materials. Waste materials are divided into municipal solid waste (MSW) and industrial solid waste (ISW) (Dastbaz & Cochrane, 2019). According to Shah et al. (2021), approximately 2,01 billion tonnes of MSW are generated, of which only 33% are properly disposed. Accordingly, developing strategies for energy utilisation from waste products is vital to decrease environmental impact.

Company X consider sustainable and continuous development values as essential in manufacturing development. Therefore, energy production is based on environmentally friendly processes generating energy and steam from a plant, burning mainly waste materials from the production. In addition, projects within energy recovery are committed to improving energy efficiency and decreasing the dependency on fossil fuels.

2.4 Literature Review Summary

Chapter 2 gives a comprehensive introduction and review of past scientific research on the topic for writing this thesis. In summary, the review concludes that manufacturing improvements regarding energy management, smart manufacturing, and automation are currently essential for companies. Furthermore, the review shows that extensive research and development are ongoing in transitioning to more efficient, sustainable, and economic operations to fulfil future requirements and targets. These future requirements and targets can be achieved by developing efficient energy management systems with automated manufacturing control, measurements, and visualisation methods.

3 Methodology

The methods used for the data collection are presented in this chapter. The primary approach for the research was a qualitative study, including semi-structured interviews with different stakeholders. Figure 18 presents a classification of the participant in the qualitative study.

The following steps describe this project's execution.

- Research proposal presentation.
- Weekly meetings with supervisors.
- Conduct research.
- Implementation of the designed system.
- Present paper versions for supervisors.
- Final research presentation.

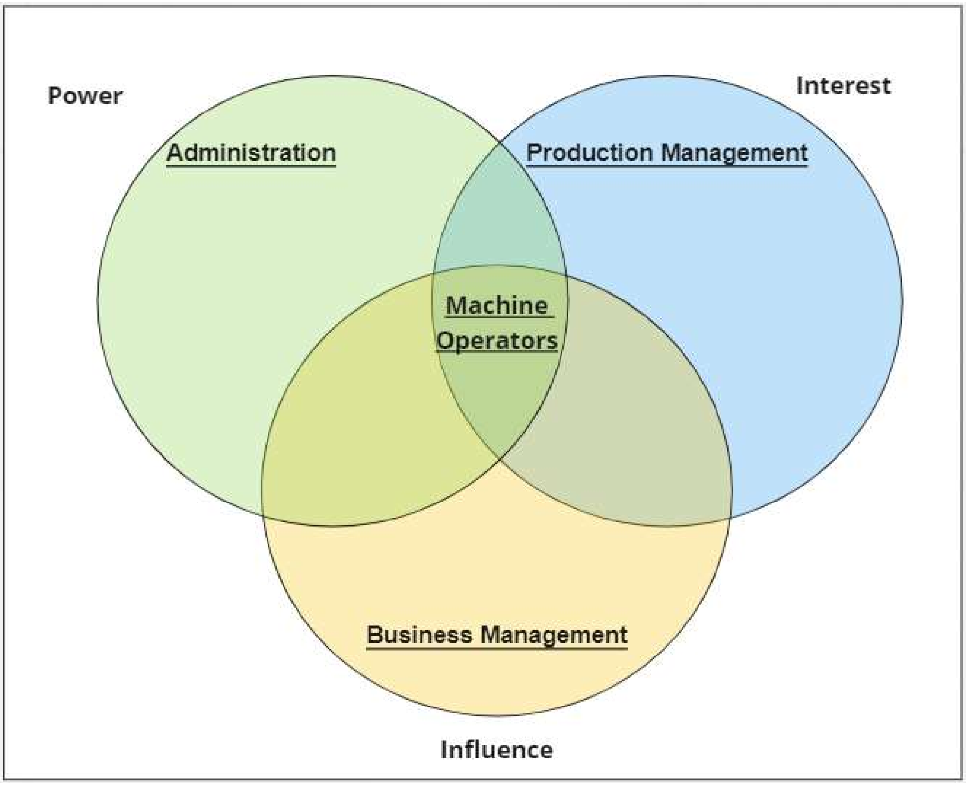

Figure 18. Stakeholder classification.

3.1 Data collection

The data collection chapter in this research focuses on information about the current manufacturing process and identifies future improvement possibilities. Furthermore, to improve energy efficiency, the data collection focuses on important energy parameters for the manufacturing process. Furthermore, stakeholders may expect different layouts, information, and reports from the energy management system. Therefore, the empirical research includes interviews with individuals from each stakeholder group, targeting essential features for the dashboard design for better understanding from people working close to the machine. These stakeholder groups are machine operators, production- and business management and administration representatives.

3.2 Qualitative research

Since the 1980s, qualitative research has been an essential applied method in social sciences. Today, qualitative research is one of the most frequently used research methods (Brinkmann & Kvale, 2018). Bhandari (2022) explains that qualitative research is utilised for collecting and analysing a large amount of non-numerical data and is effectively used to generate further ideas or to improve insight into the research problem. Furthermore, qualitative research is used to understand, describe, and explain real-world problems. The research process involves analysing the experience of groups or individuals, communication, interaction, or documents (Brinkmann & Kvale, 2018).

According to Brinkmann & Kvale (2018), conducting interviews in qualitative research is a general approach. Turner (2014) asserts that interviews can collect experience and information on a topic successfully. There are three main types of qualitative design approaches, informal conversational interview, general interview guide, and standardised open-ended interview (Turner, 2014).

In informal conversational interviews, the questions are not predetermined. Instead, they are dependent on spontaneously generated questions in a natural interaction. This lack of structure makes the interview flexible and unique based on questions created during the interview. Still, this type of interview is often considered unreliable and unstable due to inconsistency in the interview questions and the risk of bias in the collected data (Turner, 2014).

The General interview guide is a more structured approach that offers some freedom to change structure when conducting the interview. Furthermore, the approach ensures that the interview treats the same topic with all participants while there is the opportunity to add unique questions with every interviewee (Turner, 2014).

The third and stricter approach is the Standardised Open-Ended interview, where the same questions are asked to every participant. Still, the open-ended structured questions ensure open-ended answers where all participants can express emotions, experiences, and opinions. According to Turner (2014), the most used interview approach is Standardised open-ended interviews in research studies. The reasons are the characteristics open-ended questions provide.

The fourth interview approach is a closed, fixed-response interview, where the questions have predetermined answer alternatives for the participant. A closed, fixed-response approach is functional when the interviewer has limited interviewing experience. In this research, both research approaches are used and combined. In other words, some questions are open-ended, and some are closed-fixed with predetermined alternatives.

3.3 Conducting Qualitative interviews

In the qualitative study, are interviews with the semi-structured architecture used. The semi-structured approach is a method for data collection based on a thematic framework, and the questions are decided beforehand without determining the order. The semi-structured interview is used for flexibility and to have the opportunity to ask additional questions (George, 2022).

Conducting a professional and well-structured qualitative interview requires some crucial phases. The first part of the interview is the planning phase, where the interview is prepared. During the preparation, the research objective is to be clarified by considering the survey questions of why, what, and how. This stage clarifies the next stage of the survey, the research purpose and focuses on why the research is relevant.

The next step is to design the interview guide with topics or questions. Essential features to consider are simplicity, clarity, and phrasing, described in the three main steps below.

1. Thematising is used to formulate research questions and clarify the investigated theme.
2. Identify the participants for the research. George (2022) lists several main sampling methods for finding appropriate participants for the interview. In order to find the most suitable participant with knowledge about the research topic, the most suitable sampling method is expected to be the Purposive sampling method.
3. Sampling bias is essential when choosing participants, meaning some population members are more represented than others.

The following phase is to choose the medium and start conducting interviews. When conducting semi-structured interviews, avoiding biases is essential when asking follow-up questions. Furthermore, consider interview conditions, body language and expressions to remain the questions unbiased.

After conducting the interview, the next step is to write a transcript and analyse the collected data. The transcription can either be verbatim, where all sounds are included or intelligent verbatim, where grammatical issues and fillers are excluded. In addition, the thematic analysis is conducted to identify patterns and frequently appealing ideas and give a preliminary overview of the collected data. After organising the themes, there are two main analysing approaches for analysing semi-structured interviews. The first approach is the inductive approach, with a general conclusion based on specific observations. The second analysing approach is the deductive approach, with a more specific conclusion based on general information (George, 2022). Finally, the findings from the data analysis in this research are presented in the result chapter. Due to data security reasons, the interview transcript is not published in this research. Instead, Chapter 5.1 presents common patterns and themes among the responses.

4 Data visualisation

This chapter presents the next part of the empirical research, visualising data. The number of data collection systems for performance measurements in energy-related cases has increased in recent years. Based on the qualitative study, the practical implementation includes designing an energy management system with collection assets and a visualisation dashboard in a program. The dashboard design relies on simulated and measured data for visualisation, which include presenting data in graphs, chart, and tables.

4.1 Collecting assets

The first step of creating the energy management system is collecting data for analysis. This research focuses on implementing different sensors and flowmeters in the manufacturing process. Sensors measure essential condition parameters from the manufacturing, such as temperature and humidity. Flowmeters are sensors used to measure condensate and steam flow ratings, utilised by calculating their energy consumption. In addition, electricity consumption measurements could be improved by smart electricity meters implemented for every part of the manufacturing process.

Hardware and software technologies control the collecting assets. A common term used for controlling industrial assets is operational technology (OT). Dochita (2022) defines operational technology as the combination of physical devices and software that enable control and monitoring of manufacturing processes. Traditionally, OT consists of supervisory control and data acquisition (SCADA) systems and programmable logic controllers (PLC). This research proposes PLC and a Modbus RTU working as controllers, receiving signals from sensors and flowmeters. According to Mellado & Núñez (2022), PLC has been the central unit in industrial control systems during the increasing automation in manufacturing.

4.2 Litmus Edge

Litmus Edge is the software used for planning the proposed management system in this research. The software needs to fulfil the requirement of the proposed management system. In research by Mahmudova (2021), Litmus Edge is listed among the ten most used IoT software during 2021 and the only comprehensive platform for data analytics, collection, management, and integration. Litmus Edge enables efficient IoT systems in industrial manufacturing, and the platform offers features to improve efficiency through complete advanced solutions adapted for the Industry 4.0 generation.

Some useful tools for effective implementation are real-time analytics of IIoT Data, advanced analytics, and pre-processed data at the edge. Furthermore, the program ensures security through controls and isolations between customers and projects. According to Litmus Automation (2022), Litmus Edge (Figure 19) is a complete computing platform, effectively providing analytics and integrations for several industrial assets. In addition, the edge manager improves the overview of manufacturing performance and tools for solving emerging problems more accurately.

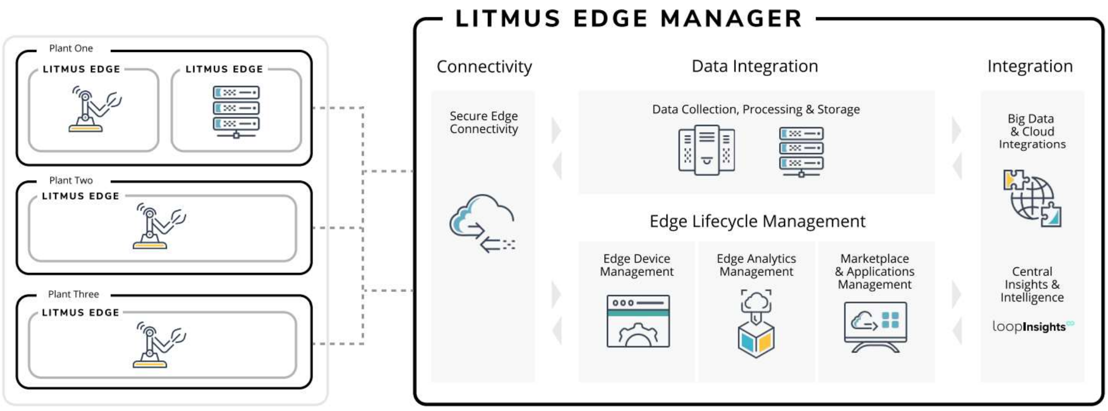

Figure 19. Litmus Edge Manager architecture (Litmus Automation, 2022).

4.2.1 Node-RED

The programming language used in Litmus Edge is Node-RED. Node-RED is a programming environment developed by IBM engineers with a flow manager optimal for IoT solutions in several operating systems. Furthermore, the open-source Node-RED environment offers features for connecting older SCADA interfaces and protocols with new, more practical protocols customised for industrial implementations (Nițulescu & Korodi, 2020).

Node-RED programming relies on JavaScript, connecting software and hardware in a virtual layout with drag-and-drop nodes. In addition, Node-RED support several databases for storing collected data that can be further analysed and visualised in dashboards. Ferencz & Domokos (2019) point out Node-RED as an efficient programming platform for industrial implementations due to its flexible features for product prototyping and dashboard tools with several charts.

4.2.2 InfluxDB

The collected energy data must be stored in a database for further analysis. Accordingly, a time-series database called InfluxDB is utilised in this research. InfluxDB is a well-established, open-source database developed for processing writing and query loads. In addition, InfluxDB offers a platform which is efficient for integration with other software able to store real-time data. InfluxDB suits application metrics, sensor data in IoT systems, and operation monitoring. InfluxDB is a pre-installed application in Litmus Edge and is, therefore, suitable for edge data analytics (Ren et al., 2021).

4.3 Grafana

The tool used for the dashboard design visualising measured data in this research is Grafana. Grafana is a web-based tool for visualising datasets and setup custom dashboards (Chooruang & Meekul, 2018). In addition, Grafana is effectively connecting several database sources like InfluxDB and Graphite, where collected data is stored. Torkel

Odegaard created Grafana in 2014 as an open-source program enabling dashboard visualisation, data storage, and query (Chakraborty & Kundan, 2021). In addition, Grafana offers several pre-built monitoring dashboards. Furthermore, Grafana provides functions for detecting problems in the manufacturing process, which alerts the operator with essential information (Ren et al., 2021).

Chakraborty & Kundan (2021) introduce several essential features in Grafana for visualising metrics in histograms, heat maps, and graphs. In addition, Grafana unifies numerous data sources and possibilities to extend existing features with more platforms and tools, creating an extensive entirety. Other features are flexible collaboration possibilities through sharing or publishing a dashboard with co-workers and reliability by alerting the user with warning messages if any false occur to the system. In addition to the open-source version, Grafana Cloud and Grafana Enterprise are available upgrades. The cloud software enables high scalability, availability and storage running on a public cloud, while the Enterprise version offers more features suitable for companies (Chakraborty & Kundan, 2021).

5 Result

The result section includes interview analysis, dashboard design proposals and an energy storage system improving energy recovery from the manufacturing process. The interview analysis present patterns and themes among the responses used as baseline for the dashboard design.

5.1 Interview result

The interviews included 11 participants, separated into four different stakeholder groups. Among the participants were three operators from the same machine, three from production management, and four participants representing business and administration management. All participants in the interview are stakeholders with interest and influence on the manufacturing process, providing essential knowledge for this research.

Q1. What are your operational tasks?

The first fundamental question gives insight into the background of every participant. Furthermore, the purpose is to identify how the research affects their work. After reviewing all answers, based on their operational tasks, four main stakeholder groups, including machine operators, business managers, production managers, and administrators, are represented in the interview.

Q2. What energy resources are you monitoring, and how do you measure them?

During the interview, a prominent pattern of responses is the shortage of existing measurement methods. Currently, monthly reports present the total consumption of electricity and different fuels. Accordingly, it is difficult to identify actual energy-consuming factors and how to improve energy efficiency. Furthermore, a limitation is that collected data should be shared or reported between stakeholders because of the need for more accurate visualisation.

Q3. What advantages could real-time measurements of energy consumption bring?

The responses include several positive factors by implementing real-time measurements. Common patterns are improvements in the overview of the energy consumption to identify failures, better possibilities for accurate actions and improved efficiency. Other advantages among the responses are improved and customised production cycles providing information about differences between different products, and identifying any changes more accurately.

Q4. What information do you expect the dashboard to provide?

The dashboard design should provide real-time data, trends, and a view of details in energy consumption. In addition, it is important to compare total consumption with produced products in manufacturing. Furthermore, the dashboard could enable predictive maintenance, reduce manufacturing costs, and improve production planning.

Q5. What type of layout and graphs could be effective?

By introducing some alternative graphs and tables, the participants had the opportunity to propose their opinion of the visual layout. The visual impression is crucial to ensure a practical understanding of the collected data. The responses concluded that clear and suitable graphs and tables are essential. Accordingly, the most preferred graphs among the responses were line-, pie- and comparison charts.

Q6. How could real-time monitoring of energy consumption help your daily work?

Every management participant considered real-time monitoring of energy consumption to be relevant. Furthermore, staying competitive and leading is critical when developing automation and connectivity. Still, among the machine operators, the impact of their daily work is expected to be low.

Q7. How could automation improve energy efficiency?

By automating the manufacturing process, management representatives considered operational decisions and helpful tools to identify high energy-consuming factors as vital factors. The production managers highlighted the importance of awareness for the operator and analysing tools for production cost calculations. The business management representatives see automation topics like big data as helpful to adequately visualise manufacturing processes.

Q8. Can you describe current energy consumption reporting and where the energy losses emerge?

The current insight provided to business management needs to be improved. The current monthly energy consumption data provides a limited general overview of total energy consumption for the business- and production management. The machine operators note that they are not reporting anything regarding energy consumption. Energy losses occur during the manufacturing process from non-isolated steam pipes, heating and drying, and when starting the machines.

Q9. Regarding environmental requirements and laws, what future improvements are essential from an energy perspective?

The main pattern in the answer is the green transition to more sustainable and renewable energy resources. Among the administration representatives, reliable data to report to authorities is essential. In addition, rising energy prices increase the importance of improving energy efficiency and working against EU climate targets.

Q10. What other types of performance indicators are important in energy reports?

Other suggested performance indicators necessary for energy reporting are productivity factors, six sigma analysis, and efficiency measurements of manufacturing performance. Comparing produced products with consumed energy during manufacturing could be utilised for product calculation and optimising production cycles.

Q11. Finally, do you have any other advice that could be essential for the thesis?

The purpose of the final question was to finalise the interview and to allow the participants to add any additional information for the research. The responses included short conclusions and interest in further discussions in the future.

5.1.1 Interview summary

The first stakeholder group is machine operators, who work closest to the machine and have broad knowledge about manufacturing. For them, alarms and information about any exceptions in temperature or humidity during the manufacturing process are essential. The second stakeholder group is production management, which is responsible for leading the manufacturing process. The research concludes that production management mainly focuses on energy consumption per produced product to plan production more effectively and optimise production cycles. Furthermore, information about energy consumption for every product group could improve the accuracy of product prices. The third stakeholder group is business management. Business management is interested in identifying economic aspects of energy consumption in manufacturing. These are costs per line, energy performance factors, and other cost-related parameters to conduct accurate actions and decisions. The fourth stakeholder group is participants from the administration, settling many vital decisions regarding energy questions. In conclusion, a view of details and trends combined with an overview of the total energy consumption is vital for the administration.

5.2 Energy Management System (EMS)

The target for this work is to develop a system that can measure accurate data and visualise it on a dashboard. In order to generate sufficient data to the dashboard is an energy management system based on an IoT structure developed. The system (Figure 20) enables efficient data collection, controlling, analytics, storage and finally visualisation.

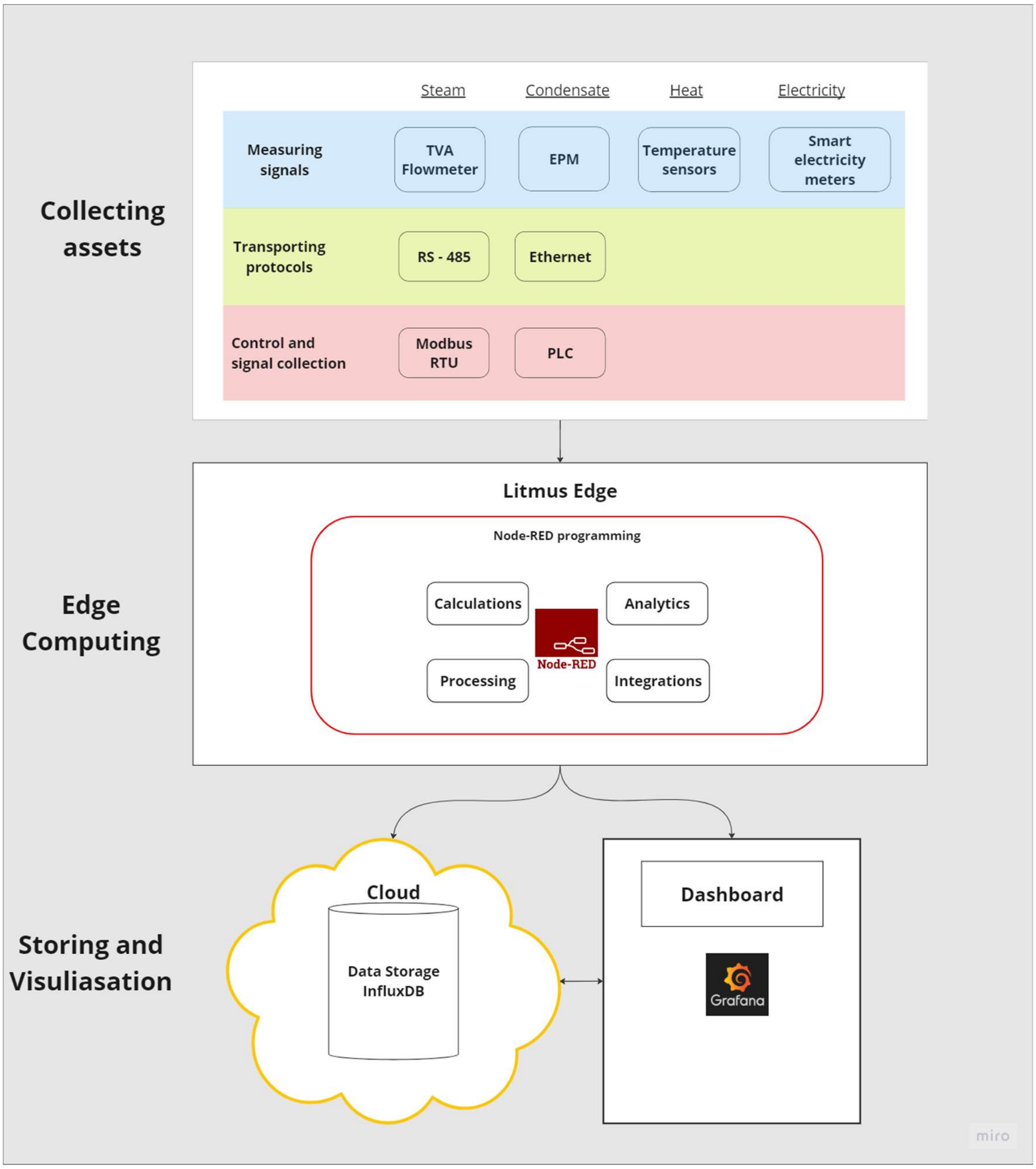

Figure 20. Energy Management System (EMS) architecture.

In the first part of the system above, collecting assets measure and collect data from several parameters in the manufacturing process. The collection asset section is divided into three layers. The first layer measure data through sensors, TVA flowmeters, EPM, and smart electricity meters. A target variable area (TVA) flowmeter is utilised for collecting accurate and reliable measurements of steam flows in the manufacturing process.

The EPM is an electronic pump monitor that can be implemented for measuring condensate volumes. All data is then sent through different protocols, for example RS-485 protocol in a Modbus RTU communication is used for transferring steam data from the TVA flowmeter. Other collected data are controlled by a PLC.

The second part of the energy management system is the edge level, where data is sent from the collecting assets to Litmus Edge through Ethernet connection. The edge layer enables data processing, integration and energy calculations. Furthermore, data analytics are available in the edge to improve the overview of the performance of the manufacturing process.

In the third part, the processed data is visualised and stored. Litmus Edge is connected to an InfluxDB database, used to enable visualisation in dashboards. The resulting dashboards are developed in Grafana, and the design includes three separate layouts, developed by considering requirements for all stakeholder groups.

5.3 Dashboard design

The dashboard needs to ensure reliable, secure, and flexible visualisation of the data, which can improve control and regulation of energy consumption in real time. Furthermore, the dashboard design should provide a clear overview of the manufacturing performance, where defects and malfunctions should be quickly identified and solved. Product differences could be identified based on real-time energy monitoring, enabling more accurate product cost calculations. In addition, any price changes in the energy market could be more flexible, adapted and used to develop existing energy cost models. Finally, the system could improve the planning of future investments and improvements.

The proposed dashboard design provides a view of details, trends and performance indicators based on real-time measured data. A significant result of the system based on real-time energy monitoring is identifying differences between product groups enabling more accurate product cost calculations. In addition, any price changes in the energy market could be more flexible, adapted and used to develop existing energy cost models. The interview result in Chapter 5.1 shows some differences among the stakeholders regarding expected information and reports in the dashboard. Accordingly, the research includes three dashboard designs customised for the target group.

The designed dashboard for machine operators is presented below (Figure 21). The dashboard provides machine operators with an efficient user interface that collects all essential values in one location. Graphs identifying deviant values and alarms alert the operator, enabling more real actions to prevent malfunctions. In addition, the dashboard is flexible, secure, and available for the operators in the production area. All graphs in the dashboard can be expanded and opened separately for a better overview of the values and trends. At the top of the dashboard are current energy consumption values from electricity, heat, steam and condensate measured in kilowatt-hours (kWh). Equation 1, introduced in Chapter 1.7, calculates the energy consumption. The values are presented in gauges with threshold values alerting the operator in case of radical high energy consumption. In addition, graphs are describing the current energy consumption and a time series visualising historical trends from several fuels in manufacturing utilised. These fuels are LPG, propene, biogas, and oil.

Under the energy consumption section graphs with measured and simulated temperature and humidity values are presented. It includes measured temperature values for all zones of the industrial heating process. The operator can optimise the heating process by identifying temperature data in real-time, reducing energy consumption, and improving manufacturing efficiency. According to Pask et al. (2017), industrial heating applications are responsible for 20% of all consumed industrial energy.

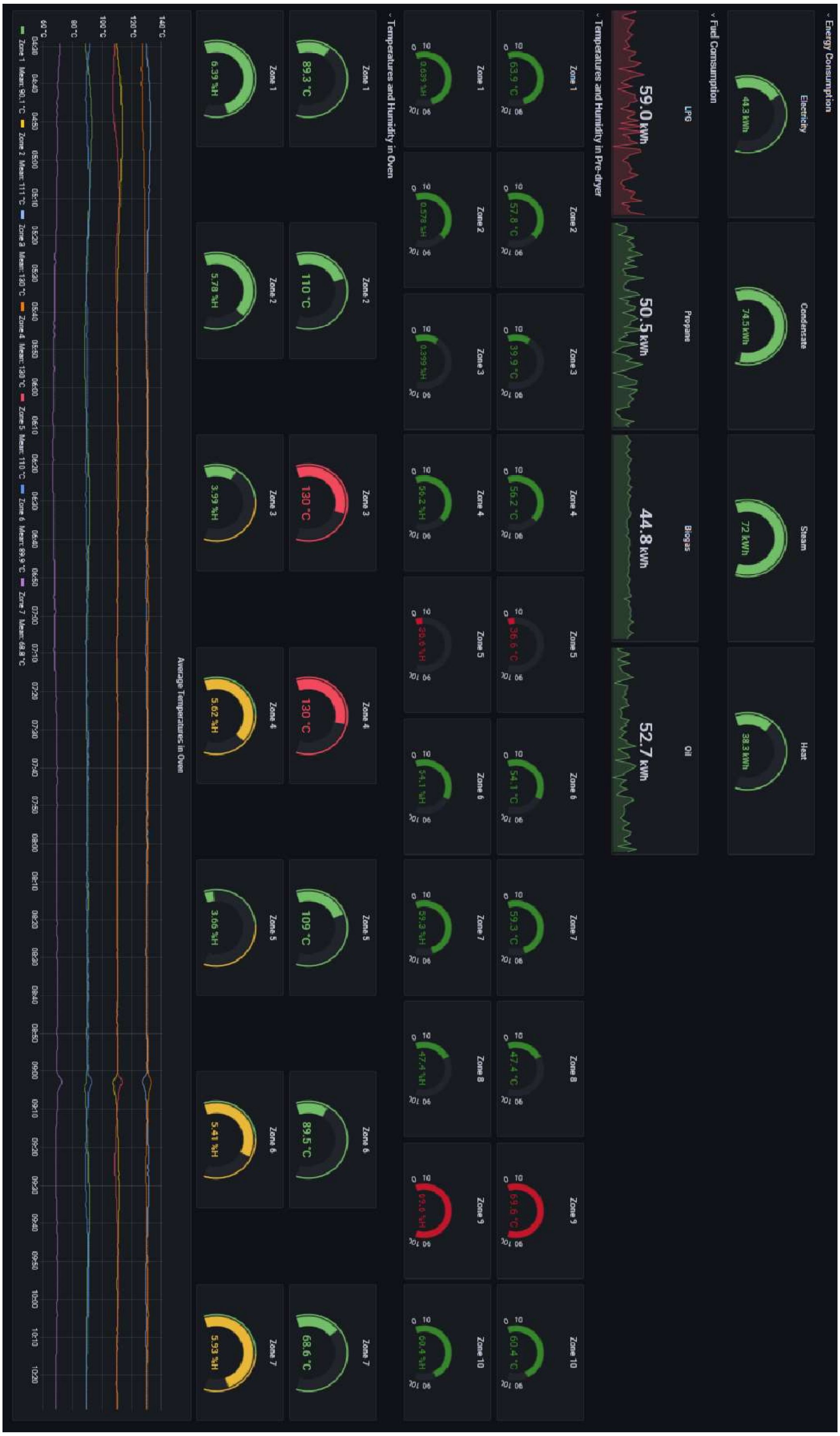

Figure 21. Dashboard for machine operators.

The second dashboard is customised for production management. The dashboard provides information supporting the production management leading the manufacturing process. More accurate planning and prediction can be adapted considering production and maintenance by identifying helpful information. In addition, alarms and warning signs alert at any critical values, radical changes, or malfunctions, enabling predictive maintenance.

The dashboard design is presented in Figure 22. The first section provides the same values as the machine operators describing all energy-consuming factors. On the other hand, the dashboard provides a more extensive overview of the energy consumption in different parts of the manufacturing process. Next, the production management desire tools to compare different energy consumption from products different products. Therefore, by separating collected energy consumption data between manufactured products, energy consumption could be compared. An implemented product comparison graph with a bar gauge simulates possible energy-consuming values.

The final section includes several essential cost performance indicators presented in Chapter 2.2 (Table 1). Exceptionally, at Company X, the produced number of products is measured in m^2, therefore replacing Tons used in some of the indicators in the table. The indicators provide the production management with information for evaluating the manufacturing process. The first indicator is Specific Energy Cost, describing the total energy cost per produced material. Second, energy intensity describes the per cent of energy consumption from a particular product compared to total energy consumption. Value-specific energy consumption focuses on the ratio between total energy consumed and total revenue. The final cost performance indicator is Specific Energy Consumption (SEC), introduced in Chapter 1.7 (Equation 3), which determines the energy ratio used to produce a product during a specific time.

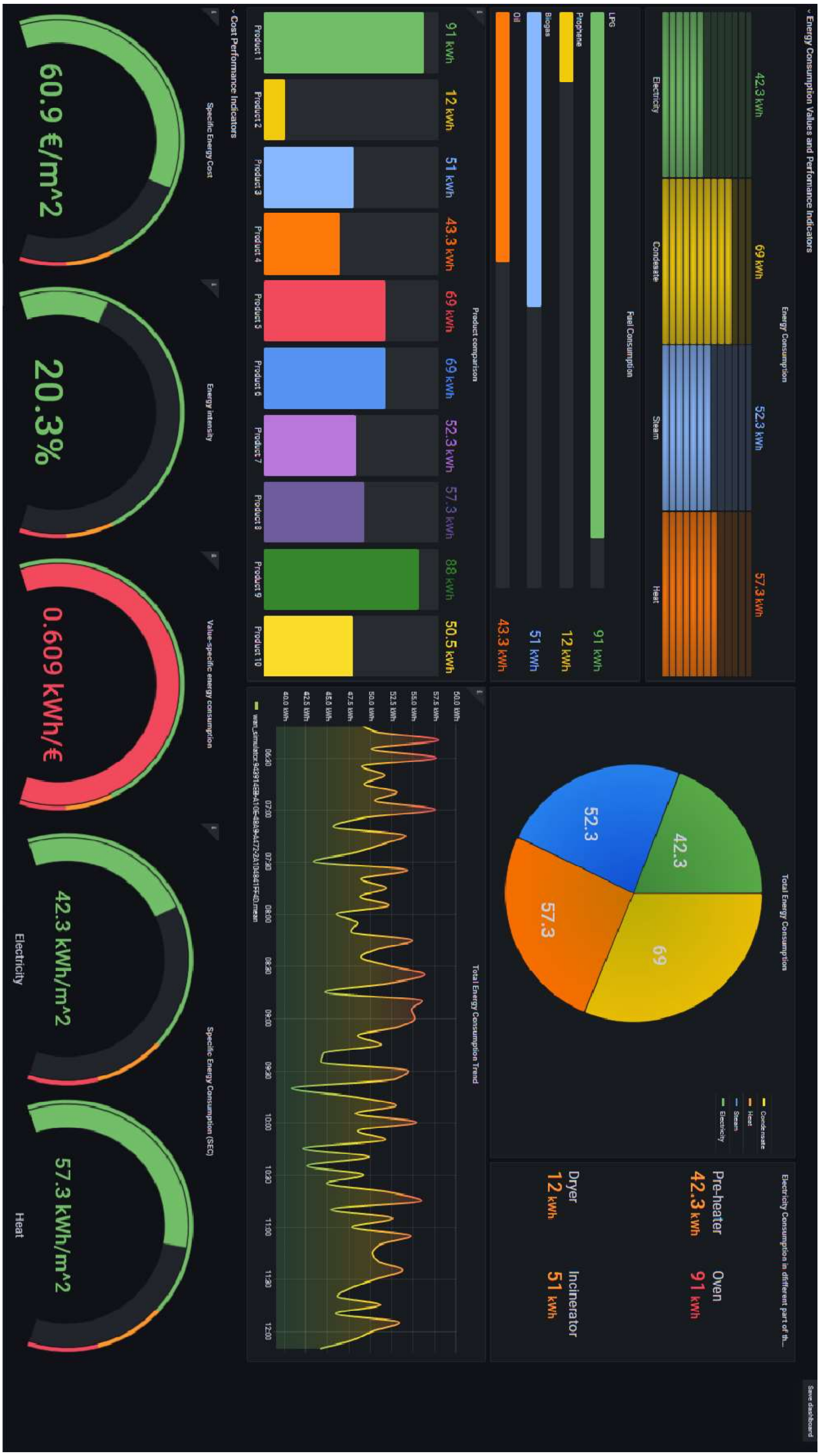

Figure 22. Dashboard design for production management.

The third designed dashboard is for business management and administration. The dashboard should support the management in making sustainable decisions by providing essential information. Therefore, the dashboard includes several performance indicators measuring key values of manufacturing. In addition, the dashboard provides the current and historical trends in total energy consumption. The energy consumption is presented in total and separated into percentages describing the contribution of every energy carrier.

Beyond the performance indicators presented in the dashboard for production management, the third design includes more values supporting future investments and improvements. For example, a graph visualising the recovery rate could be essential when improving energy recovery from the process in the future. Furthermore, the dashboard includes time series for the energy intensity of a product and specific produced products. Another essential performance indicator is CO2 emission tons per year. The dashboard design is presented in Figure 23 below.

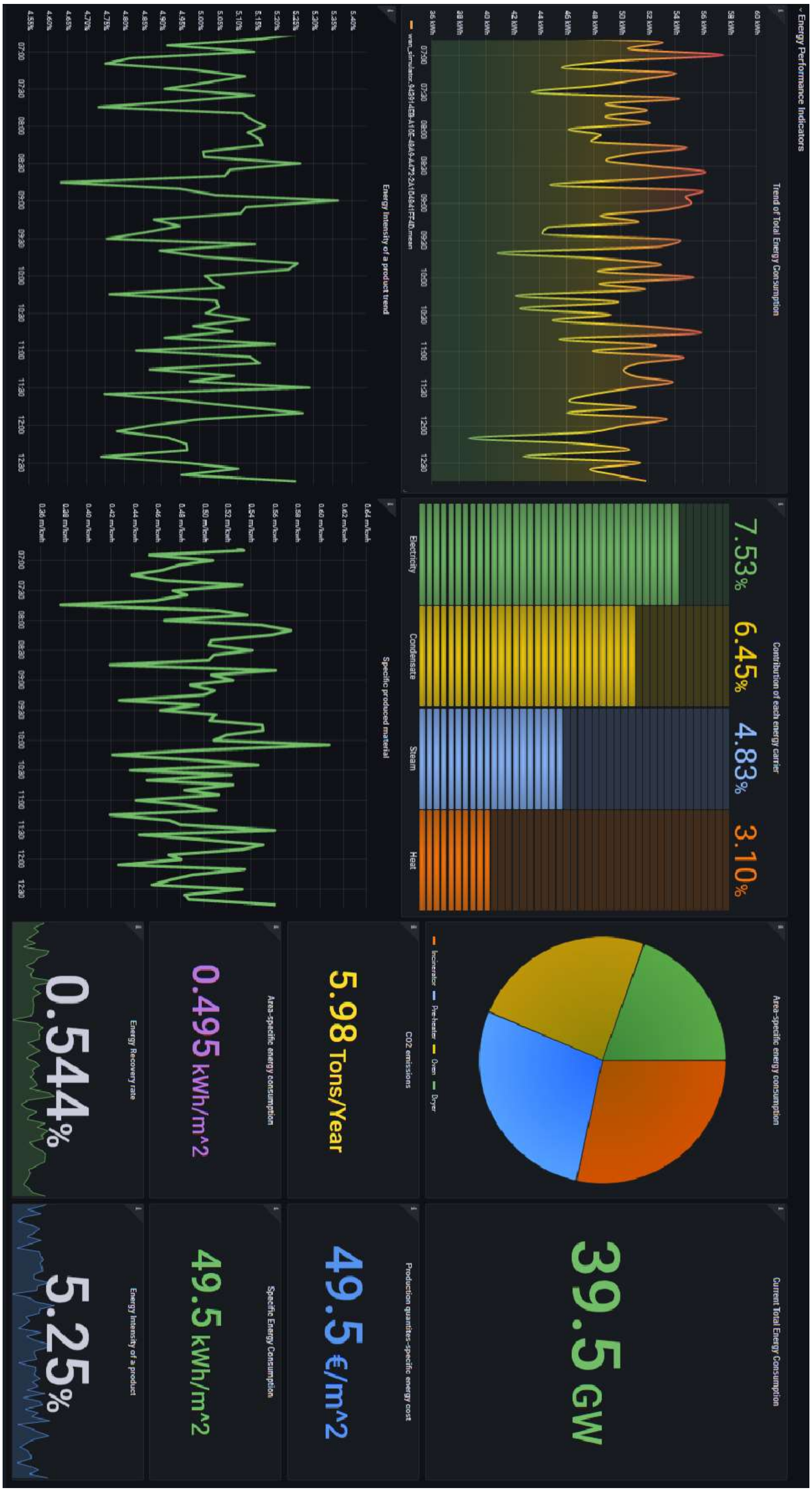

Figure 23. Dashboard for business management and administration.

5.4 Energy recovery and storage

A thermal energy storage solution with sand as a storage medium is proposed for energy storage. This type of solution is chosen because of the many benefits found during this research, which are listed below.

- Low maintenance cost.
- High-temperature capabilities.
- High energy storage capacity.
- Price and access to sand material.
- Simple technology.

Furthermore, sand is already used in the company's manufacturing, improving availability. In addition, this research investigates if waste sand from the manufacturing process could be reused as storage material. After a discussion with experts at the company, it was concluded that metallic chemicals in the sand after the production process could be an issue. Still, this could be investigated further in future research. Other drawbacks are listed below.

- Large space requirements. In order to fulfil the needed energy demand, the steel containers should contain hundreds of tonnes of sand which require extensive space. The required space issue could be solved by locating the sand battery underground.
- High energy demand. Another factor to consider is the high energy required to warm the sand to the required temperatures of 500-600 degrees Celsius. The target of creating a sustainable and efficient storage system requires that the primary energy is produced from renewable energy resources. In addition, recovered waste heat could be used as secondary energy resources.

- No electricity storage. The proposed thermal energy storage with sand is not able to store electricity. On the other hand, electricity can be produced by implementing a conversion system. Thus, this would increase costs and energy losses.

Recovered energy could be stored in the proposed storage system and utilised again. Currently, toxic waste from the manufacturing process is transported to an incinerator, where the burning process produces clean air that is only utilised on a small scale. Instead, the recovered energy in the hot air is transported to the proposed storage system and stored by warming the sand. By using waste heat as a secondary energy resource, the heating efficiency of the storage system could be increased. The stored energy could then be utilised for pre-warming ovens used in manufacturing or by warming the facility. Still, the economic aspects of the storage system should be further investigated in the future.

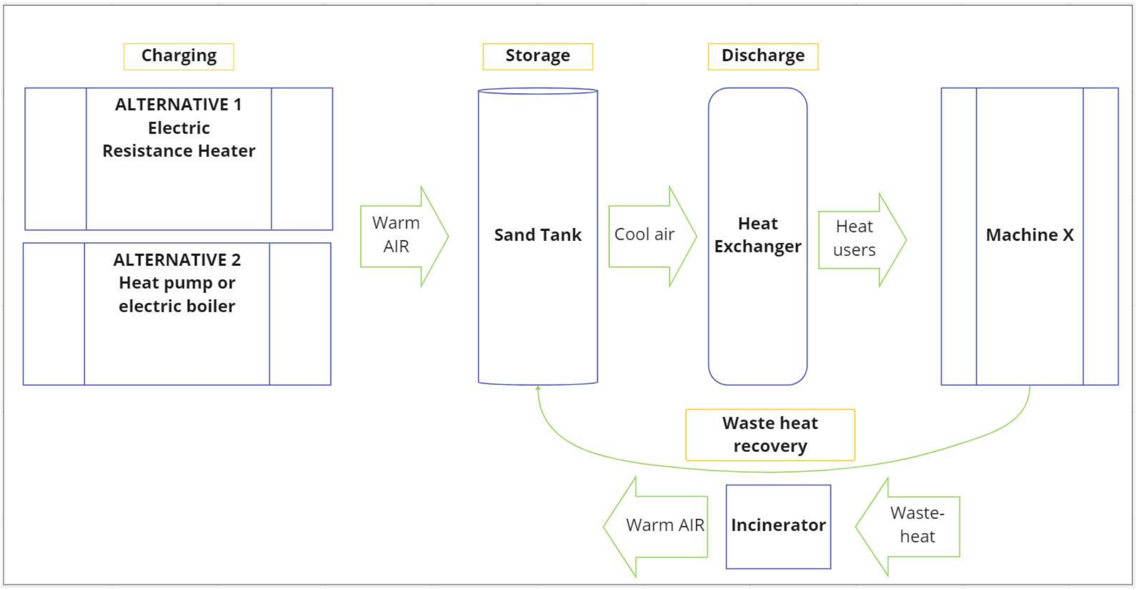

Figure 24. Energy storage and recovery architecture.

The first step of energy storage is charging, where the system generates energy, and this research investigates two possible solutions. The first alternative is based on electricity from renewable energy resources fed through resistors. The heat from the resistors is heating air, then transporting hot air forward into the sand tank through pipes. The second alternative relies on heat pumps or an electric boiler converting renewable electricity to heat, warming the air. Both alternatives would improve the utilisation of more renewable energy in the future.

Air with high temperatures would then flow through pipes in a sand-filled container. The energy is transmitted to the sand and stored in the warm sand as a thermal storage. The energy is then discharged by blowing in cold air, transported through a heat exchanger, and used as water or steam in manufacturing. Waste heat from the machine is then transported to an already-operating incinerator, removing toxic gases. Finally, clean air from the incinerator can be transported back to the storage tank and recovered. By reusing recovered energy, the primary energy demand in the system decrease, and the energy efficiency of the manufacturing process increase.

6 Discussion

The research problem considers optimising energy consumption by developing an energy management system, including data collection, controlling, and analytics. Furthermore, this thesis set out to develop a dashboard for visualisation based on accurate real-time data.

The main finding regarding the current situation is the shortage in measuring and reporting energy data. Accordingly, this research proposes an improved solution to give all stakeholders access to real-time operational data. The solution is an energy management system with energy measuring and dashboards visualising essential energy consumption values and performance indicators. Furthermore, the resulting system is based on recent IoT and Edge computing technologies to improve energy efficiency and increase energy recovery in the manufacturing process.

6.1 Theoretical implications

This work shows that an energy management system with dashboards can be successfully developed by involving stakeholders in the development process. The research is relevant for developing more intelligent manufacturing with more automation. The implicated system follows the relevant aspects of smart manufacturing defined by Rathnam (2019) in the theoretical part. The implicated system offers a wide range of opportunities for energy consumption analytics and improvement possibilities for energy efficiency. Furthermore, the system targets to increase energy recovery and storage driven by renewable energy resources improving manufacturing sustainability.

6.2 Limitations

Although the research has achieved its objective, there are some limitations to consider. First, due to limited time and delays, the dashboard has not been implemented and tested in the manufacturing. Instead, the designed system in this research is mainly based on simulated values of how the final dashboard layout could be visualised. In addition, the collection assets in the manufacturing is restricted to current measurement methods. Thus, this research proposes recommendations of what could be developed and implemented in the future. In addition, this research is not considering the economic aspects of the proposed system. This research is also constrained to energy measurements in the manufacturing process at the machine, while other energy consuming factors in the building are not considered.

6.3 Future research possibilities

The changing energy sector demands continuous further research. From the interview result, it is clear that measurement and reporting possibilities should be further investigated in the future. Furthermore, future research could identify other performance indicators that effectively improve the overview of the manufacturing process. In addition, the proposed system could be implemented and evaluated. The implemented system could be used for comparing different product groups and planning production cycles in the future. In summary, this research can be a baseline for future investments, energy consumption analytics, and manufacturing performance evaluations.

7 Conclusion

In conclusion, this research investigates improvement possibilities regarding the overview of energy consumption in manufacturing. This chapter summarises the research and provides answers to the following research questions:

- How to improve energy consumption measurements?
- How could energy recovery rates increase?
- What kind of energy management system could be implemented to improve energy consumption efficiency?
- How could real-time collected data be visualised from the manufacturing process?
- What layouts, information, and reports should the dashboard provide from different stakeholder perspectives?

The first research question regarding possible improvement possibilities for measuring and monitoring energy consumption is an essential part of this research to investigate. The research shows several existing technologies and developing solutions for this purpose. The conclusion is through automation, developing a smart factory system which connects hardware, software and programs collecting measured energy data. The measurements are executed by sensors, flowmeters, and monitors and then controlled and utilised by software programs.

This research concludes that energy recovery rates could increase by implementing a storage system, where energy from the manufacturing process is transported, stored, and utilised. The energy would mainly consist of excess heat from the production that could be utilised as a secondary energy resource, improving the energy efficiency of the storage system. In addition, the storage system could benefit the transition to more sustainable energy production by using renewable energy resources for heating the storage medium.

The energy management system in this research focuses on how energy consumption data can be collected, processed, stored, and visualised in different dashboards. The system collects assets that collect and measure energy parameters in the manufacturing process. The data is then managed, processed, and analysed by an edge platform in a software program called Litmus Edge. Finally, the data is stored in an InfluxDB database and visualised in dashboards through graphs, charts, and tables in Grafana.

In other words, the proposed energy management enables collected real-time data from the manufacturing process to be visualised. The proposed dashboards are based on simulations that effectively visualise energy consumption and essential performance indicators. Still, the number of implemented collection assets in manufacturing is limited and must be expanded to satisfy future requirements completely.

The preferred layout information and reports provided by the dashboard are concluded to be different based on the targeted stakeholder group. This research question was answered by conducting qualitative interviews with different stakeholders. The participants were separated into four main stakeholder groups to conclude the main themes and patterns in the response. In conclusion, common for all stakeholder groups is that line and pie graphs are the most efficient way of visualising the information. In addition, by utilising the knowledge and experience of all stakeholder groups, the proposed dashboards are more customised and suitable for them. Finally, this research was appreciated and considered important for all stakeholder groups and a milestone for the improvement of energy efficiency in the manufacturing of Company X.

References

Arfa, M., Nilawar, N., Misba, A., Dayyan, M., & Nadaf, M. (2019). *Heat Storing Sand Battery*.

Bhandari, P. (2022, November 24). What Is Qualitative Research? | Methods & Examples. *Scribbr*. https://www.scribbr.com/methodology/qualitative-research/

Brinkmann, S., & Kvale, S. (2018). *Doing interviews* (Vol. 2). Sage.

Broberg Viklund, S., & Johansson, M. T. (2014). Technologies for utilization of industrial excess heat: Potentials for energy recovery and CO2 emission reduction. *Energy Conversion and Management*, *77*, 369–379. https://doi.org/10.1016/j.enconman.2013.09.052

Chakraborty, M., & Kundan, A. P. (2021). Grafana. In M. Chakraborty & A. P. Kundan, *Monitoring Cloud-Native Applications* (pp. 187–240). Apress. https://doi.org/10.1007/978-1-4842-6888-9_6

Chen, K.-C., & Lien, S.-Y. (2014). Machine-to-machine communications: Technologies and challenges. *Ad Hoc Networks*, *18*, 3–23. https://doi.org/10.1016/j.adhoc.2013.03.007

Chooruang, K., & Meekul, K. (2018). Design of an IoT Energy Monitoring System. *2018 16th International Conference on ICT and Knowledge Engineering (ICT&KE)*, 1–4. https://doi.org/10.1109/ICTKE.2018.8612412

Dastbaz, M., & Cochrane, P. (Eds.). (2019). *Industry 4.0 and engineering for a sustainable future*. Springer.

Directorate-General for Energy. (2020, March 18). *In focus: Renewable energy in Europe*.

Dochita, L. (2022, July 12). Introducing Operational Technology Asset Management. *Lansweeper*. https://www.lansweeper.com/cybersecurity/introducing-lansweeper-ot-operational-technology-asset-management/

Ferencz, K., & Domokos, J. (2019). Using Node-RED platform in an industrial environment. *XXXV. Jubileumi Kandó Konferencia, Budapest*, 52–63.

George, T. (2022, November 30). *Semi-Structured Interview | Definition, Guide & Examples*. https://www.scribbr.com/methodology/semi-structured-interview/

Gerodimos, A., Maglaras, L., Ferrag, M. A., Ayres, N., & Kantzavelou, I. (2023). IoT: Communication protocols and security threats. *Internet of Things and Cyber-Physical Systems*, *3*, 1–13. https://doi.org/10.1016/j.iotcps.2022.12.003

IRENA. (2019). *Innovation landscape brief: Renewable power-to-heat*. International Renewable Energy Agency,.

Janes, A., Sillitti, A., & Succi, G. (2013). Effective dashboard design. *Cutter IT Journal*, *26*(1), 17–24.

Javied, T., Bakakeu, J., Gessinger, D., & Franke, J. (2018). Strategic energy management in industry 4.0 environment. *2018 Annual IEEE International Systems Conference (SysCon)*, 1–4. https://doi.org/10.1109/SYSCON.2018.8369610

Javied, T., Rackow, T., & Franke, J. (2015). Implementing Energy Management System to Increase Energy Efficiency in Manufacturing Companies. *Procedia CIRP*, *26*, 156–161. https://doi.org/10.1016/j.procir.2014.07.057

Lawrence, A., Thollander, P., Andrei, M., & Karlsson, M. (2019). Specific Energy Consumption/Use (SEC) in Energy Management for Improving Energy Efficiency in Industry:

Meaning, Usage and Differences. *Energies*, *12*(2), 247. https://doi.org/10.3390/en12020247

Li, J., Herdem, M. S., Nathwani, J., & Wen, J. Z. (2023). Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management. *Energy and AI*, *11*, 100208. https://doi.org/10.1016/j.egyai.2022.100208

Li, Z., Lu, Y., Huang, R., Chang, J., Yu, X., Jiang, R., Yu, X., & Roskilly, A. P. (2021). Applications and technological challenges for heat recovery, storage and utilisation with latent thermal energy storage. *Applied Energy*, *283*, 116277. https://doi.org/10.1016/j.apenergy.2020.116277

Litmus Automation. (2022). *We Bridge The Gap for Industrial IoT* (pp. 1–4). https://cm6b2d.p3cdn1.secureserver.net/wp-content/uploads/2020/11/Litmus-Edge-Platform.pdf

Maguire, E. (2018). *The Intelligent Edge: Opportunity and IoT Innovation*. Momenta Partners AG. https://www.momenta.one/hubfs/Resources/Whitepapers/Downloads/WP-Intelligent-Edge-PDF-LIVE.pdf

Mahmudova, S. (2021). INTELLIGENT SYSTEMS FOR THEINTERNET OF THINGS: ESSENCE, PERSPECTIVES AND PROBLEMS. *International Journal of Natural Sciences Research*, *9*(1), 17–25. https://doi.org/10.18488/journal.63.2021.91.17.25

Mellado, J., & Núñez, F. (2022). Design of an IoT-PLC: A containerized programmable logical controller for the industry 4.0. *Journal of Industrial Information Integration*, *25*, 100250. https://doi.org/10.1016/j.jii.2021.100250

Miró, L., Gasia, J., & Cabeza, L. F. (2016). Thermal energy storage (TES) for industrial waste heat (IWH) recovery: A review,. *Applied Energy*, *179*, 284–301.

Murray, C. (2022, April 7). *Vattenfall starts filling up 200MW thermal storage tower in Berlin*. https://www.energy-storage.news/vattenfall-starts-filling-up-200mw-thermal-storage-tower-in-berlin/

Nițulescu, I.-V., & Korodi, A. (2020). Supervisory Control and Data Acquisition Approach in Node-RED: Application and Discussions. *IoT*, *1*(1), 76–91. https://doi.org/10.3390/iot1010005

Paraskevopoulos, D. (2022). *IoT Communication Protocols Adoption Report 2022*.

Pask, F., Lake, P., Yang, A., Tokos, H., & Sadhukhan, J. (2017). Industrial oven improvement for energy reduction and enhanced process performance. *Clean Technologies and Environmental Policy*, *19*(1), 215–224. https://doi.org/10.1007/s10098-016-1206-z

Poulose, T., Kumar, S., & Torell, G. (2022). Power storage using sand and engineered materials as an alternative for existing energy storage technologies. *Journal of Energy Storage*, *51*, 104381. https://doi.org/10.1016/j.est.2022.104381

Qiu, T., Chi, J., Zhou, X., Ning, Z., Atiquzzaman, M., & Wu, D. O. (2020). Edge Computing in Industrial Internet of Things: Architecture, Advances and Challenges. *IEEE Communications Surveys & Tutorials*, *22*(4), 2462–2488. https://doi.org/10.1109/COMST.2020.3009103

Rathnam, L. (2019, June 7). *Industry 4.0: Building the 'smart factory' of tomorrow—Today*. https://techgenix.com/smart-factory/

Ren, S., Kim, J.-S., Cho, W.-S., Soeng, S., Kong, S., & Lee, K.-H. (2021). Big Data Platform for Intelligence Industrial IoT Sensor Monitoring System Based on Edge Computing and AI. *2021 International Conference on Artificial Intelligence in Information and Communication (ICAIIC)*, 480–482. https://doi.org/10.1109/ICAIIC51459.2021.9415189

Schaeffer, E. (2017). *Industry X.0: Realising digital value in industrial sectors*. Kogan Page.

Schmidt, C., Li, W., Thiede, S., Kornfeld, B., Kara, S., & Herrmann, C. (2016). Implementing Key Performance Indicators for Energy Efficiency in Manufacturing. *Procedia CIRP*, *57*, 758–763. https://doi.org/10.1016/j.procir.2016.11.131

Shah, A. V., Srivastava, V. K., Mohanty, S. S., & Varjani, S. (2021). Municipal solid waste as a sustainable resource for energy production: State-of-the-art review. *Journal of Environmental Chemical Engineering*, *9*(4), 105717. https://doi.org/10.1016/j.jece.2021.105717

Sufiyan, T. (2022, November 24). What is Node.js: A Comprehensive Guide. *Simplilearn*. https://www.simplilearn.com/tutorials/nodejs-tutorial/what-is-nodejs

Turner, D. (2014). Qualitative Interview Design: A Practical Guide for Novice Investigators. *The Qualitative Report*, 754–760. https://doi.org/10.46743/2160-3715/2010.1178

Wegner, P. (2023). *IoT Signals—Manufacturing Spotlight*. Microsoft Intel.

Yrungaray, A. (2022). Edge Computing to Improve Operations. In *Smart Manufacturing* (pp. 411–414). https://doi.org/10.1002/9781119846642.other7